FOR DISCUSSION PURPOSES

BRITANNIA CONTAMINATED SITE INVESTIGATION

FAN AREA REMEDIATION PLANNING DOCUMENT BRITANNIA MINE SITE, BRITISH COLUMBIA

Prepared for

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EXECUTIVE SUMMARY

URS Norecol Dames & Moore (URS) was retained by the Province of British Columbia to complete a Remediation Plan of the Britannia Mine Fan Area. URS conducted a Detailed Site Investigation (DSI) and ecological and human health risk assessments of the site prior to this Remediation Planning Document.

Britannia Mine is a former copper mine that, at the height of its production, was the largest copper mine in the British Commonwealth. The site is located approximately 50 km north of Vancouver on the east shore of Howe Sound near Squamish. Mine operations resulted in the deposition of sulphide tailings into Howe Sound over a period of approximately 70 years. Acid rock drainage (ARD) generated in the extensive underground workings discharges directly to Howe Sound. ARD-impacted groundwater and surface water also discharges to the Sound from the Fan Area. These mine water discharges continue to this day.

The Fan Area is part of the former Britannia Mine in Britannia Beach, British Columbia. The BC Ministry of Water, Land and Air Protection (BCMWLAP) and the federal Department of the Environment (DOE) are leading an initiative to prevent the discharge of contaminated waters to the Sound, and to bring the mine site into compliance with provincial and federal regulations. The Site is currently under BCMWLAP Remediation Order OE-16907.

Recent site investigations have identified the extent and nature of contamination within the Fan Area. Although metal contamination is widespread, the most impacted locations are found in areas of historic mining activity, generally in the southern half of the Fan Area (South Fan). Contaminated media on site include soils and groundwater, plus waters and sediments, both freshwater and marine. Primary Contaminants of Concern (COCs) are copper and zinc, but depending upon the specific media type, also includes antimony, arsenic, cadmium, chromium, lead, selenium, silver and tin.

ARD-impacted water discharging from the Fan Area is the result of the interaction of inflowing waters with mine wastes. These mine wastes include concentrates, sludges, low-grade ores, tailings and waste rock. Acid generation and metals leaching has likely been occurring at the Britannia site since the initiation of mining and mineral processing on the site. Acid generation and metal leaching from the site will likely continue for hundreds, and potentially thousands, of years.

Risk Assessments for the Fan Area indicated no Human Health risk. However, there is a potential for adverse effects to some ecological receptors in both terrestrial and aquatic environments on or near the Site.

Results of the Site investigations indicated that groundwater discharge rates were on the order of 100-2700 m^3/day in the North Fan and 300-1400 m^3/day in the South Fan. An independently derived water balance estimated average similar groundwater flows of 460 m^3/day in the North Fan and 1374 m^3/day in the South Fan. Average daily surface water flows are estimated to be 122 m^3/day in the North Fan and

339 m^3/day in the South Fan. Fan Area stormwater discharge to Howe Sound for the maximum-recorded rainfall event is estimated to be approximately 13,000 m^3/day.

A volume of 140,130 m^3 of mine waste is estimated to be present above the groundwater table in the Fan Area. Metal loadings from surface sources of mine waste account for approximately 43% of the metals loading to Howe Sound. Subsurface deposits contribute approximately 56% whereas loading from the Mill Building may represent less than 1% of the loading to Howe Sound. Deposits of concentrates, copper launder sludges, tailings and ores. Waste rock and mixed mine waste /fill are the least significant sources.

The long-term time scale of the potential impacts is significant, and elevates the difficulty in finding suitable remedial measures that will stand the test of time. Therefore, permanent solutions that mitigate or eliminate the risk must be considered along with contaminant control and containment solutions.

URS has developed this Remediation Planning document according to a risk-based remediation approach. Risk assessments carried out to date were utilized to develop a site-specific remedial objective for the Howe Sound receiving environment. The governing risk management objective is to increase habitable areas in the aquatic environment by reducing the discharge of toxic constituents in a cost effective manner. URS proposes that a remedial option (or combination of options) be implemented that results in reducing the flux of copper such that the concentration of copper at an initial dilution zone of 5 metres from the groundwater discharge interface of the Fan Area is less than 4 µg/l. Based on our estimates of copper and zinc flux from the South Fan Area and the mixing model, we believe that a 77% reduction in the present flux of contaminants of concern would be necessary to achieve this objective. Caution needs to be exercised in the translation of the aquatic objective to an upland remediation objective. The proportion of impact from each individual source is not well understood at this time. Therefore, a performance-based approach to implementing risk management is recommended. This will permit the risk management and remediation activities to be monitored and the progress towards achieving the receiving environment risk management objectives to be determined.

With the establishment of risk management objectives for the site, it will be possible to reduce risk to the receiving environment in an expedient, but also practical and cost effective, manner that is acceptable to BCMWLAP and the Britannia technical and community stakeholders. These remedial activities centre on controlling source areas and the exposure pathways that contribute metal loading to the receiving environment. Progressive remediation of the Site is proposed concurrent with ongoing monitoring to assess the performance of the remedial activities. Remediation of the site would be concluded once the Site remedial objectives are achieved.

In order to achieve these objectives, URS assessed potential remedial activities for risk reduction from groundwaters, surface waters and soils in the Fan Area. These activities included source removal, water diversions, capping and groundwater collection and treatment. These activities are considered the best available and practical techniques for reducing terrestrial and marine impacts from the Fan Area. URS recognises that external variables such as other remedial actions, additional data, or stakeholder and public requirements for remediation may influence the final design.

Captial costs and present value (PV) costs were estimated for feasible remedial activitites. Risk reduction for each remedial alternative was estimated based on calculated potential reductions in metal loading to Howe Sound.

Preferred remedial options were selected for the North Fan and South Fan areas. Selection was based upon their ability to reduce contaminated groundwater and surface water discharges to the receiving environment, cost and permanence of the solution. For the South Fan, a program of progressive remediation is proposed that utilizes a combination of surface and selective subsurface source removal, plus water diversions and soil capping. For the North Fan, a similar program of progressive remediation using surface source removal, water diversions and soil capping would be employed to mitigate impacts on the receiving environment. Performance-based monitoring of the receiving environment would be utilized to measure the benefit of the remedial activities.

URS believes that remedial activities can be instigated well before the Britannia Mine water treatment plant is scheduled to begin operation in spring 2004. The performance of these remedial actions will be assessed by ongoing monitoring to determine if the current remediation is sufficient. URS proposes that the low cost, less invasive remedial activities (e.g. diversions and surface source removal) should be completed within several months of Plan implementation. This would result in immediate and significant reductions in metals loading to Howe Sound. More extensive, costly or invasive remedial activities would be implemented following consultation with stakeholders and the public.

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1.0 INTRODUCTION

1.1 PROJECT OVERVIEW

URS Norecol Dames & Moore (URS) was retained by the British Columbia Ministry of Water, Land and Air Protection (BCMWLAP) to develop a Remediation Plan (RP) of the Britannia Mine Fan Area (identified as the Fan Area or the "Site"). This Remediation Planning Document summarizes the findings of the Fan Area Detailed Site Investigation and Risk Assessments, reviews the regulatory aspects pertinent to remediation of the Site, reviews, compares and contrasts potential remediation options to ensure compliance with applicable standards and regulations, and provides a framework for further remediation plan development and implementation of remediation at the Fan Area.

The Fan Area is part of the former Britannia Mine in Britannia Beach, British Columbia. BCMWLAP and the federal Department of the Environment (DOE) are leading an initiative to prevent the discharge of contaminated waters to the Sound, and to bring the mine site into compliance with provincial and federal regulations. The Site is currently under BCMWLAP Remediation Order OE-16907.

Britannia Mine is a former copper mine that, at the height of its production was the largest copper mine in the British Commonwealth. The principle environmental concern associated with the Site is acid rock drainage (ARD) containing elevated concentrations of dissolved metals in mine water discharge, surface runoff, Britannia Creek and groundwater. The management of source materials and impacted surface runoff and groundwater are the focus of this remediation plan.

Other environmental protection initiatives currently underway by others include:

- Mine hydrology: determining potential storage capacity of the mine for use in conjunction with the water treatment plant, and determining potential water diversion and mine in-flow reduction strategies (SRK Consultants);
- Water treatment plant preliminary design: determining the best method to treat the mine discharge (AMEC consultants);
- Flood hazard analysis: determining the nature of flood and debris flow hazard of Britannia Creek and recommending mitigative measures (Water Management Inc.); and
- Mine water containment: installation and monitoring of 2200 level adit plug (Britannia Mine Remediation Corporation).

As part of this contract, and leading up to the development of this remediation plan, URS completed a Stage I Preliminary Site Investigation (PSI) for the Fan Area and Additional Areas (URS, 2002a). Subsequently, a Detailed Site Investigation Work Plan (URS, 2002b) was developed, in conjunction with input from various stakeholders, and in consideration of a Screening Level Ecological and Human Health Risk Assessment (URS, 2002c) to describe the approach required to complete the DSI for the Fan Area. The Fan Area DSI (URS, 2002d) documented the assessment of the Fan Area soils and sediments, groundwater, storm water and surface water completed by URS in 2001/2002. The Britannia Fan Area Tier 1 Ecological Risk Assessment (URS, 2002e) and the Britannia Fan Area Human Health Risk

Assessment (URS, 2002f) evaluated the respective potential risks resulting from the presence of contaminated soils, surface water and groundwater.

1.2 Remediation Planning Concept

This Remediation Planning Document has been developed using a risk-based approach. It is URS's goal to recommend and implement a remediation strategy that reduces the risk to human health and the environment in the most efficient, cost effective way that is also acceptable to the various project stakeholders. These stakeholders include BCMWLAP, Environment Canada, Britannia Mine Remediation Corporation, the BC Mining Museum, Squamish Regional District, and the Britannia Mine Remediation Technical Advisory Committee (TAC).

Under the BC Contaminated Sites Regulation (CSR), the two main approaches to remediation are the contaminant concentration approach and the risk-based approach. The contaminant concentration approach removes contaminants such that the residual contaminants are present at concentrations less than the applicable CSR standards for the site's existing or intended land use. A risk-based approach utilizes risk assessment to define the magnitude of the environmental risk relative to accepted threshold effects values for various receptors, and then, through the application of control measures, the risk is reduced to less than the threshold value. Granted that removal of receptors is generally not a desirable approach, the most common method of reducing risk is to reduce or remove the source of the risk (the contamination) or reduce or eliminate the pathway of exposure between the source and receptor. This document has been developed on the basis of implementing a risk-based approach, by considering source and pathway controls, ultimately leading to a reduction in the risk posed to the receiving environment.

Remediation of the Britannia Fan Area is complex; there are numerous overlapping interests and stakeholders whose desires for future development of the area will have to be considered in combination with the technical aspects of the mine and Fan Area remediation. For example, there are other aspects of the mine remediation that may affect the scope of the Fan Area remediation. The proposed mine water treatment plant project, the Britannia Creek flood mitigation project, the Official Community Plan and prospective redevelopment of the area must all be considered if an effective plan is to be developed and implemented. In our assessment of the available options, URS has considered technical applicability as well as potential suitability to stakeholders. We recognize that the most expedient or cheapest alternatives may not be the best approach to all stakeholders, nor the best alternatives with regard to approach, permanence of the remedial solutions or on-going maintenance costs. Therefore, as required by the CSR, we have also provided an overview of a stakeholder consultation process to be followed to obtain stakeholder consensus.

1.3 Establishing Risk-Based Remediation Objectives

The conclusions of the Tier 1 ecological risk assessment (ERA) (URS 2002a) indicated that there is the potential for adverse effects to both terrestrial and aquatic ecological receptors both on terrestrial portions of the Britannia Mine site as well as in the aquatic habitat in adjacent water bodies. This risk is related to the presence of mine wastes on land and in the intertidal and subtidal zones, and the discharge of impacted groundwater and surface water into the adjacent water bodies.

The recently conducted DSI (URS 2002b) has documented the extent to which terrestrial and aquatic portions of the Site have been substantially "modified" by past mining activities. The magnitude of impact of the Site has been so extensive that there is no practical way of restoring the Site to former pre-mining conditions or to remediate environmental media on the site to meet CSR standards or other appropriate environmental quality criteria at a reasonable cost.

For this reason the remediation of the Site will be conducted in accordance with risk management principles as set forth in the CSR. This remediation plan generally conforms to the guidelines provided in the CSR definitions. The facts supporting the remediation plan originating from the DSI are summarized, various remedial options are evaluated, compared and contrasted, and desirable approaches are recommended. However, this plan varies from a standard plan in that some options appear to be suitable for immediate implementation, whereas other options will require stakeholder consultation and consensus prior to proceeding. This plan has been designed as performance-based, phased approach where the effectiveness of actions are measured against the established remedial targets.

The initial step in developing a risk-managed site remediation is the development of risk management objectives, recognizing that the overarching objective is to ensure the sustainability of populations and communities of ecological receptors potentially impacted by the contaminants at the Site. As stated in the BC Guidance on Ecological Risk Assessment (BCMELP 1998), *"For environmental receptors... the goal is not to protect each individual from any toxic effect, but rather to protect enough individuals so that a viable population or community of organisms can be maintained."*

The proposed risk management objectives take into account the fact that the magnitude of impact is such that total return to pre-mining conditions is impractical. The risk management objectives also consider that while remediation will significantly improve conditions for ecological receptors on or in proximity to the Site, there will be the potential for continuing, although minor, ongoing impacts for a substantial number of years.

Therefore, the environmental assessment studies and risk assessments completed by URS and others to date have been synthesized by this remediation plan. The plan proposes risk management objectives for the Britannia Mine designed to be protective of the identified receptors at risk, namely aquatic organisms. Measurable performance criteria based upon the magnitude of habitat areas that exceed ecological effects concentrations for appropriate environmental media or provincial standards or criteria are proposed by this plan. For example, areas in the foreshore where groundwater discharges into surface water will be defined by the spatial extent of surface water that exceeds the surface water effects level. This is similar in concept to defining the initial dilution zone for the offshore mine water discharge, or for that matter, where subtidal tailings or "sediment" left in place will exceed the sediment quality guideline (or other appropriate effects level). While a number of potential risk management and remediation activities were evaluated and summarized in this report, URS has also provided what we believe is the most effective approach to risk management and remediation in the Fan Area.

2.0 BACKGROUND

2.1 SITE CHARACTERISTICS

2.1.1 Site Location

The Britannia Mine Site is located approximately 50 km north of Vancouver (Figure 2.1-1) on the east shore of Howe Sound near Squamish. The Fan Area boundaries, shown in Figure 2.1-2, represent the area designated as the Fan Area, referring to the glacial and fluvial deposits that form a fan at the terminus of Britannia Creek at the Sound. The primary buildings and locations referred to throughout the report are also identified on Figure 2.1-2.

2.1.2 Site Geology

Regionally, the Britannia Beach area is underlain by volcanic and sedimentary rocks, and intrusive rocks of the Coast Plutonic Complex. The intrusive rocks have hydrothermally altered the volcanic and sedimentary rocks resulting in the emplacement of sulphide mineralization. Sulphide mineralization in the Britannia area is hosted within a zone of shear deformation and metamorphism and consists primarily of pyrite, with lesser amounts of chalcopyrite and sphalerite and minor erratically distributed galena (MINFILE, 2001).

The Britannia Fan Area consists of a debris fan formed since the end of the last glacial period, approximately 10,000 years ago. The fan is constructed of a heterogeneous assemblage of sediments, landslide deposits and detritus originating from the Britannia Creek drainage. The uphill apex of the fan is located in the north east corner of the Fan Area, and extends to the bottom of Howe Sound.

Glacial till and colluviated sediments mantle and blanket the surrounding slopes. Bedrock is exposed at higher elevations and on steep slopes. Creek valleys are layered with often thick units of glacial sediment and more recent fluvial and landslide deposits. A terrace of steeply dipping gravels exists at the mouth of Britannia Creek, approximately 40 to 60 meters above sea-level (James, 1929). Well-bedded sands and gravel occur in the Britannia Creek valley near 650 meters elevation (James, 1929). Natural soils in the area are primarily podzolic, highly leached, acidic and reddish brown in colour (Environment Canada, 1973).

2.1.3 Areas of Environmental Concern

The Fan Area DSI defined four Areas of Environmental Concern (AECs) for the Britannia Fan Area, based upon their environmental settings and historical uses (See Figure 2.1-3). The two terrestrial AECs (AEC 1 and AEC 2) were based upon historical activities on the terrestrial portion of the Fan. Most industrial activities associated with the processing of ore from the Britannia mines took place within AEC 1. Residential/Commercial activities and limited mining-related industrial activity took place within AEC 2. Boundaries for these AECs were further refined based upon the degree of metal contamination within the site soils. AEC 3 is the reach of Britannia Creek within the confines of the Fan Area. AEC 4

is the intertidal area (to an elevation of -1 m LNT) from the mouth of Britannia Creek to the southernmost tip of the Fan Area.

Based on hydrogeologic results of the DSI the Fan Area was subdivided into two hydrogeologic regimes, the north Fan and south Fan, as shown on Figure 2.1-2. This designation follows essentially the same subdivision between AEC 1 and AEC 2, except the northeast portion of the Fan Area is included in the north Fan.

2.1.4 Site Hydrogeology

Site hydrogeology was assessed during the DSI (URS, 2002d). Groundwater flows from east to west across the Fan with lateral hydraulic gradients in the east as high as 0.03, and along the shoreline, 0.001 (in the south) to 0.014 (in the north). The mean hydraulic conductivity of shallow Fan Area soil in AEC 1 is 2.5 x 10^{-4} m/s. The mean hydraulic conductivity in AEC 2 is slightly higher at 6.9 x 10^{-4} m/s. The pump test at EX-1 gave a transmissivity (T) of approximately 1550 m^2/day, with storage of 0.015. At EX-2, T was estimated to be approximately 155 m^2/day and the storativity (S) was approximately 0.003.

Estimated groundwater flow velocities are 0.1-1.0 m/day in AEC 1 and 0.3-1.7 m/day in AEC 2. Estimated groundwater discharge rates are 100-2700 m^3/day (1 to 32 L/sec) in AEC 1 and 300-1400 m^3/day (3 to 16 L/sec) in AEC 2. Vertical groundwater velocities in AEC 1 were calculated to be in the range 0.06-1 m/day. In AEC 2 vertical groundwater velocities were calculated to be in the range of 0.07-0.5 m/day.

The water surface elevation of Britannia Creek was found to be higher than groundwater in the adjacent Fan, from 1.5 m higher in the east to 0.4 m higher in the west. This may potentially indicate recharge of Fan Area groundwater from the creek.

2.1.5 Adjacent Environment

The Britannia Fan Area is bounded to the west by Howe Sound. Forested, mountain slopes form the remainder of its perimeter. Some mining infrastructure, namely the 4100 Portal and waste dump, are located adjacent to the eastern border of the site. Britannia Creek flows along the northern edge of the Fan Area and drains a large catchment area east of the site.

Under the Britannia Contaminated Sites Investigation, lands outside of the Fan Area are referred to as the Additional Areas. Separate investigations of the Additional Areas are being carried out by URS, which will also include a separate remedial plan. URS recognises that the results of these investigations may have some influence on the remedial planning activities for the Fan Area.

2.2 Site Activities

The Britannia Mine produced primarily copper during its operating life from 1902 to 1974. Secondary products were zinc, silver, gold, cadmium and lead. Ore was mined from both open pits and underground workings. Surface and underground rail systems were used to transport ore to the mill/concentrator,

which was located on the surface at Britannia Beach. Underground transport of ore to the concentrator was used exclusively during the last 20 years of the mine operation.

Over the life of the mine, three different mill/concentrator facilities were operated. All were located in the same general location in Britannia Beach. The mills and other related mine facilities (both historical and existing) are shown in Figure 2.1-3. In general, the milling/ore concentration process was similar for all three facilities and consisted of crushing and grinding ore to the consistency of fine sand, followed by the separation of metal sulphide minerals from the other rock forming minerals using flotation cells. Flotation cells consisted of tanks of water containing reagents to facilitate the flotation of sulphides and suppression (sinking) of non-sulphide minerals. Passing the ore through a series of these cells (a flotation circuit) resulted in the concentration of sulphides by the removal of non-sulphide minerals. The sulphide-rich flotation material was then dewatered to produce a concentrate that was shipped off-site for smelting and processing. Underflow from the flotation cells, which also contained lesser, but significant amounts of sulphide, was discharged as a waste product known as tailings. Tailings have the grain size of fine sand. The tailings were discharged via a pipe or sluice into the intertidal zone of Howe Sound at various points along the shoreline of Britannia Beach, including the mouth of Britannia Creek.

Beginning in 1956, a "copper launder" was employed to extract dissolved copper from mine waters discharging from the underground workings via the 4100 portal. The copper launder was a passive system consisting of a series of concrete runways that contained scrap iron (primarily in the form of used 'tin' cans). Mine water was directed to the launder where it flowed through the scrap metal, causing the dissolved copper in the mine water to precipitate. The scrap metal was periodically physically shaken to dislodge the copper flocculants that then flowed to a lower settling pond for recovery. In addition, a sedimentation pond was located upstream of the launder to collect existing precipitates in the mine discharge before entering the launder. The precipitated copper was collected from the lower settling pond and shipped off-site for smelting. Wastewater discharged to Britannia Creek beginning in 1972. Wastewater from these facilities was transported via a concrete piping system that paralleled Britannia Creek and discharged into Howe Sound via a diffuser.

Waste rock from underground development of the mine workings was dumped at the entrance to the mine (portals). The waste rock was also employed as construction, rail ballast and roadbed material across the site. For the purposes of this Remediation Planning Document, tailings, waste rock and liquid effluents from the mining/milling process are collectively referred to as mine wastes.

2.3 FUTURE LAND USE

Current land use in the Fan Area is defined by the four AECs, which include:

- AEC 1 - present land use is industrial and commercial.
- AEC 2 - present land use is industrial, commercial and residential.
- AEC 3 and 4 are assumed to be urban parkland use.

Present use of the Fan Area includes the BC Museum of Mining and its support buildings, a few small commercial enterprises. Residential land use with AEC 2 is limited to a few small single-family detached homes/trailers.

The future use in each AEC has not been determined as yet. As per the *Official Community Planning Document* AEC 1 land use may be tourist commercial and industrial. AEC 2 land use may be tourist commercial, floodplain, and urban park. In general the current land use designations of the site will be maintained. For the purpose of the Remediation Planning Document the current land use designations allow for more conservative remedial actions than an industrial or commercial site wide land use designation.

3.0 SUMMARY OF PREVIOUS INVESTIGATIONS

3.1 PREVIOUS SOIL INVESTIGATIONS

3.1.1 2001 April, Golder Associates, Report on Britannia Creek Fan, Preliminary Site Investigation, Britannia Beach, BC

In April 2001, Golder Associates completed a PSI of the Britannia Creek fan. The purposes of this investigation were to determine if contaminants were migrating into receiving waters from the Britannia Creek fan and former mill area, and to make recommendations on remedial actions.

Soil investigations included the installation of 15 soil borings in 14 locations, which were completed as groundwater monitoring wells in February 2001. Borehole depths ranged from 1.96 to 8.84 m and showed the soils were mainly sand and gravel.

Select soil samples were analysed for metals, sulphates and acid-base accounting (ABA). Copper was detected at concentrations exceeding the CSR industrial land use (IL) standard in nine out of eleven soil samples analysed over five locations. Copper concentrations in the soil ranged from 60 to 1600 µg/g. Zinc was present in the soil samples at concentrations exceeding the CSR IL soil standard in five of the eleven samples. Zinc concentrations in the soil samples ranged from 55 to 4560 µg/g. Other contaminants of concern detected in the soil at concentrations exceeding CSR IL standards were antimony, lead and selenium.

3.2 PREVIOUS GROUNDWATER INVESTIGATIONS

3.2.1 2001, Golder Associates, Report on Britannia Creek Fan, Preliminary Site Investigation, Britannia Beach, BC

In April 2001, a hydrogeological investigation of the Fan Area was completed to study contaminant migration to the receiving waters from the Britannia Creek fan and former mill area. Fifteen monitoring wells were installed, ranging from 1.96 to 8.84 m depth. Cadmium, copper and zinc were detected above CSR Aquatic Life (AW) standards in most of the wells, with chromium, lead and selenium above CSR AW standards in some of the wells.

In the report, slug tests were used in five wells to determine the hydraulic properties and site-wide monitoring was used to determine flow directions of the system.

3.3 PREVIOUS SURFACE WATER INVESTIGATIONS

Contaminated surface water is a concern at the Britannia Mine site. Runoff flows through the underground mine workings and is acidified, dissolving heavy metals, before it flows into Britannia Creek and Furry Creek and discharges into Howe Sound. Investigations that studied surface water flows and contamination at the mine are described in the following sections.

3.3.1 A Reconnaissance Study of Acid Mine Drainage at the Britannia Mine, 1995

Price, Schwab and Hutt conducted a reconnaissance of the surface drainage of the majority of the Britannia Mine site for the British Columbia Ministry of Energy, Mines and Petroleum Resources (BCMEMPR) in 1995. Their main findings were as follows:

- The 2200 Level and 4100 Level were the mine's main sources of metal discharge into the environment, affecting lower Jane Creek, Britannia Creek and the adjacent portions of Howe Sound. The water quality was toxic to aquatic life;
- Smaller metal discharges were taking place from a number of adits, waste rock piles and other mine wastes;
- Metals have precipitated into the channels of Britannia Creek and lower Jane Creek and may be a secondary source of metals being released into the environment. The same may be said for the settling ponds; and
- The main COCs identified were copper, cadmium, lead and zinc.

3.3.2 Britannia Mines Surveys, BCMWLAP, 1984-1986 & 2001

BCMWLAP conducted freshwater and marine water toxicity surveys in 1984-1986 as well as 2001. Both Britannia Creek and the 4100 Level discharge were found to be toxic to freshwater aquatic life.

3.4 Previous Sediment Studies in Howe Sound

Environment Canada performed or contracted several intertidal and subtidal investigations near Britannia in 2001. These included the following:

- Sediment grabs and/or cores were collected from 14 subtidal and 23 intertidal stations located on the East Side of Howe Sound between Porteau Cove and Watts Point. These sediments and their associated porewater were analysed for metals. Whole sediment arsenic, cadmium, copper, lead, and zinc were reported to exceed benthic life probable effects levels (PEL). Toxicity tests (Microtox, echinoid fertilization inhibition, algae growth inhibition) were performed on the porewater and/or whole sediments. A few of the subtidal samples, and one of the intertidal samples, collected near the Fan Area and northwards past Britannia Creek towards Watts Point, demonstrated slight toxicity in one or more of the three toxicity tests. Observed toxicity did not correlate well with SEM/AVS ratios of greater than one (often a predictor for metal bioavailability).

A subtidal survey of the physical and biological features of the Britannia Beach seafloor between Minaty Bay and Watts Point was performed by Coastal and Ocean Resources Inc. (CORI) using the Seabed Imagery and Mapping System (SIMS). Details on the area's bathymetry, sediment type, and benthic biota were mapped and reported (CORI, 2002).

In early of 2002 Environment Canada and G3 Consultants collected subtidal sediment grab samples from locations similar to those in their 2001 investigation (G3 Consulting, 2002). These sediment samples were sieved for benthic macroinvertebrates, analyzed for metals, and tested for toxicity using an amphipod acute lethality test.

3.5 SUMMARY OF URS DETAILED SITE INVESTIGATION

The DSI report summarizes the results of current and historical investigations with respect to the distribution of Contaminants of Concern (COCs) in on-site soil, sediment, surface water, stormwater and groundwater and identifies key interactions between soil and groundwater that control or influence the form of the COCs and their mobility on site.

The mill building and contaminants within were not included in the scope of the DSI.

3.5.1 Contaminants of Concern

Contaminants of Concern have been identified in the Fan Area for soils, groundwater, surface waters, stormwater, marine and freshwater sediments and porewaters that exceed either the Contaminated Site Regulation (CSR) Industrial Land (IL) use standards, or other applicable provincial/federal standards. For soils these COCs include: antimony, arsenic, cadmium, chromium, copper, lead, selenium, silver, tin, zinc, and petroleum hydrocarbons. Groundwater COCs are: antimony, cadmium, chromium, cobalt, copper, lead, nickel, zinc, and petroleum hydrocarbons. COCs for stormwater discharge include barium, cadmium, copper, manganese, nickel, selenium and zinc. Freshwater COCs include cadmium, copper and zinc, whereas copper was identified as a COC for stream sediments. Marine water COCs include cadmium, copper, iron, manganese and zinc, whereas cadmium, copper, nickel and zinc were defined as COCs for marine porewater.

3.5.2 Distribution of Contaminants within the Fan Area

3.5.2.1 AEC 1

Soil

In AEC 1, soil samples associated with surface exposures of concentrate, ore and tailings were contaminated above CSR IL standards for antimony, arsenic, cadmium, chromium, copper, lead, selenium, silver, tin and zinc. Copper concentrations exceeded the standard in nearly all locations, and were over 10 times the standard in many, as shown in Figure 3.5-1. Specific contaminated locations include around the mill building, the 4100 Level sedimentation pond, the copper launder settling pond and the former precipitate storage building on the concentrate wharf area. Subsurface (>0.15 m) soil samples associated with concentrate and tailings adjacent to the mill building, in the mill settling pond and west of Highway 99 near the former concentrate storage shed have arsenic, cadmium, chromium, copper, lead, selenium, silver and zinc concentrations exceeding standards.

Samples of waste rock/ore piles on the slopes adjacent to the mill, tailings, concentrate, copper launder settling pond sediment and mill settling pond sediment were tested for acid generation and metal leaching potential (ARD/ML) by analysis of acid base accounting and leachable metals (SWEP). Nearly all soil samples are likely to be acid generating, but to varying degrees due to the 0.1 to 32% range in sulphide content. Soil samples subjected to the SWEP test also leached significant concentrations of copper, cadmium, lead and zinc, although Special Waste standards were not exceeded.

Soils containing extractable petroleum hydrocarbons exceeding CSR IL standards were found adjacent to the Pozzolon Shed/Garage building, at the foot of the mill building, and west of Highway 99 adjacent to the concentrate storage building.

Based on copper concentrations, the estimated volume of soil exceeding CSR IL standards is approximately 250,000 m^3, most of which is associated with the mill processing area and concentrate wharf area in AEC 1 (Figure 3.5-2). Contaminated soils within these areas generally extend from surface to approximately 8 m below ground surface. The slopes around the mill building contain contaminated soils up to 1 m thick. Much of the remaining contamination in AEC 1 is near surface (<0.15 m).

Groundwater

Copper and zinc are the most widespread contaminants in groundwater (Figures 3.5-3 and 3.5-4). All shallow groundwater in the Fan Area exceeds CSR Aquatic Life (AW) standards, the plume extending to 12 m below the surface of the water table. The most impacted areas are the Mill Complex and the Concentrate Wharf area west of Highway 99 (south Fan / AEC 1). High dissolved metal concentrations in groundwater underlie significant deposits of mine waste. Shoreline groundwater concentrations are highest in the south Fan, and correlate with low pH and dissolved oxygen values, high sulphate values, and widespread iron precipitation/staining. Mine waste materials in this area are actively oxidizing and being leached, and appear to represent a local source for the contaminated groundwater.

Aquifer transmissivity varies both horizontally and with depth. Where interbeds of finer-grained deposits are present, transmissivity values are lower due to lower aquifer thicknesses. The transmissivity value measured during the pumping test was 1,550 m^2/d in the south Fan (AEC 1).

Hydraulic conductivities of coarser-grained aquifer units in AEC 1 and AEC 2 are fairly consistent, within a range of roughly 10 to 200 m/d (1×10^{-4} to 2×10^{-3} m/s).

The groundwater flow gradient in the Fan Area is westerly, toward Howe Sound, and is approximately 0.03 near the top (east side) of the fan, to as low as 0.004 closer to Howe Sound where fan deposits are thickest, and transmissivity highest.

The cross-sectional area of contaminated groundwater flow beneath the Fan Area becomes shallower and smaller as Howe Sound is approached to the west due to the presence of a saline wedge (Figure 3.5-5). This results in relatively steep, upward gradients at the groundwater discharge boundary as fresh groundwater at depth flows toward the shallow discharge zone. This discharge zone was measured to be approximately 12 m thick at a distance of 25 m from Howe Sound, but is even thinner at the immediate aquifer boundary with Howe Sound.

In AEC 1, minimum and maximum ranges for lateral groundwater velocities and discharge rates along the shoreline were calculated to be approximately 0.1 - 3 m/day, and 100 – 2,700 m^3/day, respectively. The vertical upward groundwater flow velocity near the shoreline was estimated to be between 0.06 and 1 m/day in the south Fan.

Groundwater elevations were monitored continuously during the period of the initial plug test. Groundwater elevations in various monitoring wells were compared with rainfall and temperature data to assess whether there were correlations. In addition, groundwater elevations were compared to the mine water level during the plug test to assess whether a correlation existed between these parameters. The findings indicated that groundwater elevation variations appear to be dominated by rainfall and snowmelt. No discernible effect on Fan Area groundwater from the storage of water within the mine workings was observed.

Fluxes of copper and zinc via groundwater to Howe Sound were found to be the most significant of all the metal COC's, ranging from 853 to 15,448 g Zn/d and 485 to 9,738 g Cu/d in the south Fan.

3522 AEC 2

Soil

In AEC 2, soil samples with arsenic, cadmium, copper, lead and zinc concentrations exceeding standards were collected from around the perimeter of the ball field, especially on the west side. The most widespread and greatest exceedences were again related to copper concentrations, as shown in Figure 3.5-1. Subsurface samples from test pits excavated west of the ball field contained antimony, arsenic, barium, cadmium, copper, lead, selenium and zinc concentrations exceeding CSR IL standards, and were associated with a layer of pyrite concentrate.

Most of the contamination in AEC 2 is near surface (<0.15 m), although contamination associated with the former pyrite concentrate stockpile is up to 2 m thick.

Groundwater

Groundwater is less contaminated in AEC 2, particularly adjacent to Britannia Creek where aquifer recharge by Britannia Creek water is suspected (Figures 3.5-3 and 3.5-4). However, buried pyrite concentrates are a suspected source of groundwater contamination in this area.

The aquifer transmissivity in the North Fan (AEC 2) was 155 m^2/d, which is lower than the transmissivity value for AEC 1 by a factor of 10. This is thought to be due to the presence of a larger number of finer-grained bedding units in the North Fan area, which reduced the effective thickness of the aquifer portion that was influenced by the pumping well.

Hydraulic conductivities of coarser-grained aquifer units in AEC 2 are the same as for AEC 1, which is within a range of roughly 10 to 200 m/d (1×10^{-4} to 2×10^{-3} m/s). Owing to the limitations of the slug and pump tests conducted as part of this DSI, maximum hydraulic conductivities in both areas could be up to five times higher than the maximums obtained through test analyses.

In AEC 2, groundwater flow velocities were calculated to range from 0.3 to 1.7 m/day, and groundwater discharge rates from approximately 300 – 1,400 m^3/day. Vertical upward groundwater flow velocity near the shoreline in AEC 2 was estimated to be between 0.07 and 0.5 m/d.

Of all the metal COC's, fluxes of copper (Cu) and zinc (Zn) to Howe Sound via groundwater were found to be the most significant, ranging from 42 to 194 g Zn/d and 22 to 102 g Cu/d in AEC 2.

3.5.2.3 AEC 3

Surface Water

Surface and near bottom water samples from the intertidal zone over the length of the Fan Area foreshore exceeded marine aquatic life criteria for surface waters for cadmium, copper, iron, manganese and zinc. Metal concentrations were elevated in both surface water and near bottom water samples, higher in surface water than near bottom water at some locations. The surface water samples represented worst-case conditions for both groundwater release and stormwater discharge, as the samples were obtained during conditions of low tide resulting in groundwater drainage, as well as during rainfall events resulting in contaminated surface stormwater runoff discharges. Unfortunately the relative contribution of each of these with respect to the metal exceedances is undetermined, and will require further sampling or modelling as part of the development of the Fan Area water balance.

A limited number of stormwater samples were collected from three outfall pipes during rainfall events. All copper and zinc concentrations exceeded BC Approved Water Quality Guidelines (AWQG) marine aquatic life criteria. The highest concentrations occurred in Mill area drainage (AEC 1), and the lowest from AEC 2 drainage. One sampling event from the Mill area discharge reported copper and zinc concentrations comparable to the highest concentrations found in ARD/ML impacted groundwater or mine discharges from the 4100 portal. Under current site conditions, stormwater discharges represent a significant source of metals loading to the Howe Sound receiving environment.

Sediments

The BCMWLAP Level 1 Draft Criteria were applied to the intertidal sediments. All sediment samples from the intertidal zone had copper values above the regulatory criteria, whereas two of the samples had lead and zinc concentrations above the criteria. The few accumulations of sediment, and that found interspersed within the cobble/boulder bed of the intertidal zone, appear to originate from the erosion of contaminated soil, gravels and sands (tailings and waste rock) from the Fan. Porewater samples from intertidal sediments also had metal concentrations exceeding criteria for cadmium, copper, nickel and zinc.

3.5.2.4 AEC 4

Lower Britannia Creek water samples exceeded the BC Approved Water Quality Guidelines (AWQG) Freshwater Aquatic Life maximum criteria for surface waters for copper, cadmium and zinc in January 2002, post installation of the 2200 level plug.

All samples of lower Britannia Creek sediments exceeded the BCMWLAP Level 1 Draft Criteria for copper. Although most of the creek bed is a large boulder or course gravel substrate, and these finer grain sediments with elevated copper levels do not comprise much of the creek bed with respect to surface area.

3.6 SUMMARY OF URS TIER I RISK ASSESSMENTS

3.6.1 Ecological Risk

The Tier 1 ERA (URS, 2002e) evaluated the potential for Site-related chemicals of concern (COCs) in environmental media in the terrestrial and aquatic areas of the Site, including soil, groundwater, surface water (marine and freshwater), sediment and porewater, to cause adverse effects to ecological receptors.

The Tier 1 ERA utilized the same AEC definitions as the DSI. The URS Screening Level Ecological Risk Assessment (URS, 2002c) identified several metals exceeding the screening criteria and were therefore identified as COCs for risk analysis in the Tier 1. These are summarised in the following table:

Fan Area Ecological COCs	
Surficial Soil	**Britannia Creek Sediment**
Copper (AEC 1) Tin (AEC 1)	Copper Iron
Britannia Creek Water	**Intertidal Sediment**
Aluminium Cadmium Copper Zinc	Copper Lead Zinc
Intertidal Water	**Intertidal Sediment Pore Water**
Cadmium Copper Iron Zinc	Cadmium Copper Nickel Zinc

Following the selection of COCs, ecological receptors (receptors of concern or ROCs) representative of those on Site believed to have potentially completed exposure pathways to these Site COCs were selected. The ROCs for soil were red alder, soil invertebrates, American robin, Western Screech Owl, Deer Mouse, and Coastal Black-tailed deer. The ROCs for surface water were fucoid algae, benthic invertebrates, blue mussel, purple shore crab, staghorn sculpin, dolly varden, blue turnstone, double-crested cormorant, tailed frog, and river otter.

Following this, toxicological reference values (TRVs) or toxicological benchmarks, which represented concentrations of COCs that are predictive of generally "safe" levels to the ROCs, were taken from the literature and compared to the 95% UCL concentrations of the COCs found in the Site media. This resulted in a hazard quotient (HQ) that is calculated by dividing the estimated environmental concentrations (the 95% UCL) of the COCs by the toxicity reference values (TRVs). Based upon this evaluation, if a hazard quotient is a value greater than one, then exposure exceeds a known "safe" concentration for the given receptor, contaminant of concern, and exposure pathway if all assumptions incorporated in the Analysis are realised.

HQs for several ROCs potentially exposed to chemicals in environmental media exceeded a value of one. The exposure scenarios with HQs greater than one are summarised in the following table:

Contaminant of Concern	Receptor of Concern	EEC	TRV	Hazard Quotient
Surface Soil (AEC 1)				
Copper	Terrestrial plants	3062	91	33.6
	Soil invertebrates	3062	225	13.6
	American robin	3062	1691	1.8
Tin	Terrestrial plants	374	300	1.2
	Soil invertebrates	374	300	1.2
	American robin	374	270	1.4
Britannia Creek Surface Water (AEC 4)				
Aluminium	Dolly varden	119	29	4.1
Copper	Tailed frog	81.8	4.5	18.2
	Dolly varden	81.8	12.9	6.3
Zinc	Tailed frog	106	52	2.0
Intertidal Water (AEC 3)				
Copper	Fucoid algae	243	32	7.6
	Phytoplankton	243	4	60.7
	Marine amphipod	243	22.8	10.7
	Blue mussel	243	10	24.3
	Purple shore crab	243	8.8	27.6
	Staghorn sculpin	243	70.4	3.5
	Dolly varden	243	12.9	18.8
Zinc	Fucoid algae	222	100	2.2
	Phytoplankton	222	96	2.3
	Marine amphipod	222	142	1.6
	Blue mussel	222	96	2.3
	Purple shore crab	222	207	1.1
	Staghorn sculpin	222	226	1.0
Britannia Creek Sediment (AEC 4)				
Copper	Amphipod	505	28	18.0
Iron	Amphipod	27996	20000	1.4
Intertidal Sediment (AEC 3)				
Copper	Marine amphipod	886	305	2.9
Lead	Marine amphipod	127	30.2	4.2
Zinc	Marine amphipod	255	124	2.1
Intertidal Pore Water (AEC 3)				
Copper	Marine amphipod	1253	22.8	55.0
Zinc	Marine amphipod	400	142	2.8

Copper and zinc concentrations in the soil, surficial water (freshwater and marine) and sediment, as well as tin in soil, aluminium in creek surface water, iron in creek sediment and lead in intertidal sediment, resulted in hazard quotients greater than one. Some terrestrial and aquatic biota site observations in the Fan Area were consistent with the indication, based upon the hazard quotients, that there is a potential for adverse effects to certain receptors. In the opinion of the risk assessors, based upon this Tier 1 analysis, there is a potential for adverse effects to some receptors from copper and zinc and perhaps other chemicals in both terrestrial and aquatic environments on or near the Site.

Based upon the results of the Tier 1 ERA, the contaminants related to historical Site operations are not bioaccumulative. Therefore, impacts to wildlife populations through food chain transfer are not expected.

In addition, further consideration of the nature and extent of the impacts indicates that likely impacts are not of the magnitude that large habitat areas, utilized by endemic marine organisms or wildlife that depend upon them, will be impacted to the extent that the sustainability of these populations or communities is jeopardized.

Additional investigations of site usage by ecological receptors, distribution and bioavailability of Site COCs, or potential toxicity of Site COCs in soil and surface water to biological organisms could be conducted to reduce the uncertainty associated with the Tier 1 ERA. A Tier 2 Risk Assessment will recommend risk-based standards to be to obtain a Conditional Certificate of Compliance once the risk-based standards are achieved.

Further investigations are necessary into whether the observed Britannia Creek chemistry after the closure of the 2200 Level plug (Millennium Plug) continues to be influenced by unidentified mine related point source discharges of acid mine drainage or release of sediment bound metals in the creek. This investigation should also evaluate whether creek surface water metal levels and associated baseline risks will decline over time in the absence of any further creek remediation.

3.6.2 Human Health

The Phase I level Human Health Risk Assessment (HHRA) assessed the potential for adverse effects to human receptors resulting from exposure to contaminants associated with historical or current conditions at Britannia Mine. Following screening of DSI COCs, only two chemicals were selected as chemicals of potential concern (COPCs) for human health: tin in surface soil in AEC 1 and selenium in subsurface soil in AEC 2.

Following screening potential exposure pathways the human exposure scenarios considered quantitatively in this assessment were the on-site construction worker (AEC 1 and AEC 2), commercial worker (AEC 1) and child trespasser (AEC 1) exposure to COPCs in soil. All other scenarios pose no significant risk.

Three populations, commercial workers, construction workers, and child trespassers, were selected for quantitative evaluation to tin in surface soil. One population, construction workers, was selected for quantitative evaluation to selenium in subsurface soil. For all exposed populations, exposures were quantified for the soil ingestion route. No other chemicals, media, or exposure pathways were identified as a potential concern necessitating quantitative analysis.

In risk estimation, risks from different COPCs and from different pathways are combined to give an overall risk estimate in the form of an incremental lifetime cancer risk for carcinogens, and a hazard index for non-carcinogens. There were no known carcinogenic effects of the COPCs. Hazard quotients associated with non-carcinogenic effects of the COPCs via oral exposure are calculated as the ratio of intake to the chronic oral reference dose (RfD) for each COPC.

The estimated hazard indices for each scenario assessed were several orders of magnitude below one and did not exceed one, therefore the COPCs in the Fan Area do not present an unacceptable risk to any receptor of concern (construction worker, commercial worker and child trespasser). No corrective action or a more refined risk evaluation is recommended.

4.0 CONCEPTUAL FAN AREA CONTAMINANT FATE AND TRANSPORT

4.1 CONCEPTUAL SITE GEOCHEMICAL MODEL

In the Fan Area, the primary control mechanism for the generation of acidic, metal-bearing groundwater and surface water is the weathering and leaching of mine wastes in the unsaturated zone. Mine materials in the unsaturated zone are exposed to water and oxygen via air circulation and downward infiltration of oxygen-rich water. This results in the oxidation of pyrite and the production of acidic water. The acidic water percolates downwards, undergoing dissolution and buffering reactions with minerals it encounters, often resulting in the dissolution of metals. These solutions may then discharge into the receiving environment as surface runoff or infiltrate to groundwater. Under certain conditions, the solution may become saturated, causing secondary metal-bearing minerals to precipitate.

Upon reaching the groundwater table, the acidic water and its dissolved constituents mix and flow with the groundwater. Fluctuations in the elevation of the groundwater table may cause repeated dissolution or precipitation of secondary minerals along the groundwater flowpath. Oxidation of pyrite will continue within the groundwater as long as sufficient dissolved oxygen is available. Consumption of oxygen during pyrite oxidation will result in a decrease in the dissolved oxygen content of the groundwater. In general, pH will decrease and metal concentrations will increase in groundwater flowing through acid generating and metal leaching mine materials due to the net addition of metal and acidity along the flowpath. Conversely, acidic metal-bearing groundwaters that flow through a regime with available buffering capacity may experience a decrease in metal concentrations and an increase in pH. These changes will result in the precipitation of secondary minerals in this environment.

Metal chemistry of the site waters (groundwater, surface water and stormwater) is related to their source area. Waters directly derived from mineralized or mine waste sources have the highest metal concentrations, whereas water draining background areas lacking mine wastes or significant mineralization have the lowest metal concentrations. Metal concentrations of waters from mixed sources (mineralization/mine waste versus background) have a range of composition dependent upon the relative proportion of their source areas.

Data indicates that the Britannia Fan Area is transitioning towards a more mature stage of acid rock drainage and metal leaching. Carbonate minerals or other minerals with significant buffering capacity are non-existent in the Britannia mine materials. Acidic conditions and elevated concentrations of metals and major elements are pervasive in surface and groundwaters. Some mine materials appear to have exhausted their sulphide supply; however, most still retain an appreciable amount of pyrite, and significant amounts of soluble secondary minerals are commonly found within the oxidized mine materials. Field evidence and laboratory results suggest that subsurface layers of tailings and concentrate above the water table are only partly oxidized and will continue to generate ARD/ML for the foreseeable future.

4.2 PRELIMINARY FAN AREA WATER BALANCE

4.2.1 Annual Water Balance

A preliminary annual water balance was has been developed by URS to understand contributions to the Fan Area surface water and groundwater flows (Appendix A). The Fan Area receives water both as direct precipitation and from a small upslope catchment (Figure 4.2-1). This excludes the larger Britannia Creek catchment that discharges to Howe Sound along the northern boundary of the Fan. The water balance was restricted to the Fan Area and its local catchment in order to check the proportions of surface water and groundwater in the Fan Area and to evaluate the efficiency of water diversion techniques to reduce discharge of contaminated water from the site. Following the completion of the Additional Areas DSI, the water balance should be updated to include relevant information.

Assuming no net change in storage, a steady state water balance can be applied to the Fan Area:

$$P = Q + ET$$

where:

P = precipitation

Q = surface water and groundwater flow

ET = evapotranspiration

Annual average precipitation onto the Fan Area catchment was determined from Environment Canada records for Britannia Beach. These data indicate that annual precipitation averages 2164 mm per year with a standard deviation of 299.4 mm. The maximum 24-hour precipitation event (rainfall) on record was 121.9 mm. On average the Fan Area experiences 174 days per year where measurable precipitation occurs.

Evapotranspiration was estimated at 600 mm/yr and is based on estimates carried out by Environment Canada (1997) for a forested mountainous area in the Squamish region.

The Fan Area has an approximate surface area of 116,700 m^2. The upgradient catchment for the Fan Area is approximately 419,000 m^2, resulting in a total catchment area of approximately 535,700 m^2. Based on the interpretation of available groundwater data, the Fan Area consists of two flow regimes (North Fan, South Fan) with accompanying upgradient catchments. The areas for these catchments are as follows:

North Fan Catchment

North Fan	49,738 m^2
Upgradient Catchment	86,085 m^2

South Fan Catchment

South Fan	66,955 m^2
Upgradient Catchment	332,862 m^2

Based on these values, the estimated combined surface water and groundwater flows through the Fan Area from precipitation are approximately 837,741 m^3 per year. Broken down by subcatchments, these volumes are:

North Fan Catchment

North Fan	77,790 m^3/yr
Upgradient Catchment	134,637 m^3/yr
North Fan Subtotal	212, 427 m^3/yr

South Fan Catchment

South Fan	104,718 m^3/yr
Upgradient Catchment	520,596 m^3/yr
South Fan Subtotal	625,314 m^3/yr

Information on surface runoff and infiltration are not available for the site. These values have been estimated using the following assumptions:

1) In the upgradient catchments, which consist of forested shallow soils overlying granitic bedrock, surface runoff accounts for 75% of the flow. Groundwater flow through the bedrock accounts for the remaining 25%, and has been assumed to be seasonally constant.

2) In the Fan Area catchments, 75% of the precipitation (minus ET) and upgradient runoff infiltrates into the groundwater, the remaining 25% consists of surface runoff.

Using these assumptions, the estimated annual groundwater and surface water flows for the North and South Fan Areas are:

North Fan

Groundwater	167,735 m^3/yr
Surface Water	44,692 m^3/yr

South Fan

Groundwater	501,523 m^3/yr
Surface Water	123,791 m^3/yr

Average daily groundwater flows are estimated to be 460 m^3/day (5.3 L/s) in the north Fan and 1374 m^3/day (15.9 L/s) in the south Fan (Figures 4.2-2a and Figure 4.2-2b). These predicted flows are within the groundwater discharge rates estimated in the DSI hydrogeological investigation for the north Fan (300-1400 m^3/day) and south Fan (100-2700 m^3/day). Average daily surface water flows are estimated to be 122 m^3/day (1.4 L/s) in the north Fan and 339 m^3/day (3.9 L/s) in the south Fan.

Maximum Stormwater Discharge

The maximum recorded precipitation event at Britannia Beach over a 24-hour period was 121.9 mm (Appendix A). Applying the water balance model developed in the previous section indicates that during a precipitation event of this magnitude the Fan Area will receive approximately 37,000 m^3/d of runoff from the upgradient catchment (North Fan – 7,700 m^3/d; South Fan – 30,000 m^3/d). Direct precipitation on the Fan is estimated at approximately 14,000 m^3/d (North Fan – 6,000 m^3/d; South Fan – 8,000 m^3/d). Stormwater discharge to Howe Sound for this event is estimated to be approximately 13,000 m^3/d. Discharges could potentially be greater due to soil saturation from previous rainfall events.

4.3 Fan Area Groundwater Model

A three-dimensional groundwater flow model was constructed to simulate groundwater flow conditions in the Fan Area. This model was intended to be an aid in evaluating different engineering measures (pump & treat, barrier walls, etc.) to reduce metals loading to Howe Sound via groundwater. These scenarios were evaluated based on their ability to reduce impacted groundwater discharge rates.

Groundwater flow conditions in the north and south Fan areas were simulated using Visual Modflow version 2.8. The model domain was bounded to the northeast by MW01-10; Britannia Creek to the north, Howe Sound to the west, and the base of the steep slope adjacent to Highway 99 and the Mill #3 building to the south/southeast. Following the completion of the Additional Areas DSI the model should be updated to include new information obtained.

Calibration of the model was achieved by varying boundary conditions and hydraulic conductivity values to match:

1. Drawdowns measured during aquifer testing during the Fan Area DSI, as shown in Figures 4.3-1 and 4.3-2;
2. Steady state, 72-hour mean hydraulic heads measured before and after aquifer testing, which are shown in Figure 4.3-3. This head distribution closely resembles that obtained during the 72-hour Baseline Study, and that presented in Golder Associates *Britannia Creek Fan PSI* (April, 2001); and
3. Estimated groundwater inflows to the Fan, as calculated by the water balance in Section 4.2. These were estimated to be approximately 460 m^3/day and 1370 m^3/day to the north and south Fan, respectively.

   After calibration, the model-predicted drawdowns at MW01-21S and MW01-22 after 4 hours of pumping EX-1 at 108 USgpm were 10 cm and 9 cm, respectively. This corresponds with measured values of 10 cm and 7 cm, respectively. Model-generated equipotential lines showing the steady state flow condition across the Fan are presented in plan view in Figure 4.3-4. Again, this is in close agreement with measured values shown in Figure 4.3-3. Model-calculated

groundwater discharge rates across the south Fan and north Fan shorelines were 1008 and 527 m^3/day, respectively, corresponding reasonably well with the water balance calculation.

Appendix B contains further detail regarding model construction and calibration.

4.4 IMPACTS OF FAN AREA SOURCES

Sources of metal loading to Howe Sound are widespread throughout the Fan Area. Deposits of waste rock, ore, tailings, mixed mine waste/fill, plus deposits of mill concentrates and sludges are found in the Fan Area, especially within the confines of AEC 1. These mine wastes have different acid generation and metal leaching potentials and therefore different potentials for loading metals to the receiving environment.

The Fan Area DSI identified both surface and subsurface deposits of concentrates, sludges, tailings, ore and waste rock at multiple locations in the Fan Area. The DSI provided the general locations and estimated volumes (250,000 m^3) for many of these mine wastes. Based upon these findings and further review of historical information, the volumes of significant mine waste deposits have been estimated down to groundwater or low tide elevation. The distribution of these surface and subsurface materials is shown in Figure 4.4-1. Table 4.4-1 provides the estimated areas and volumes of these materials by material type and location. A based on this review, a volume of 140,130 m^3 of mine wastes are estimated to be present above the groundwater table in the Fan Area.

Modified SWEP leachate tests on these different materials and their relative metal leaching capacity expressed in terms of copper plus zinc leachability has been summarised in Table 4.4-2. In general, copper launder sludges and mill concentrates have the greatest potential for leaching metals, followed by tailings, waste rock and then mixed mine waste/fill. Location of the materials also influences their ability to leach metals. Mine wastes located on the surface are more likely to be leached due to incipient precipitation and surface runoff, whereas buried wastes are less prone to removal of their oxidation products due to the attenuation of infiltrating water by the overlying soil. Deeper deposits of mine waste may be subject to periodic flushing due to fluctuation in the groundwater table elevation. Leaching and oxidation of mine wastes below the water table are greatly reduced due to the water-saturated conditions that inhibit sulphide oxidation.

Estimates of the relative potential for metal loading from these mine waste sources are given in Table 4.4 3. These are based on the mass of the estimated primary mine waste for each area and the calculated Cu + Zn leachability per kilogram of material taken from the modified SWEP test results. The results are expressed as a percentage of the total calculated mass of leachable Cu + Zn for the entire mine waste volume. These estimates cannot be used to determine actual loadings from mine wastes, or to determine metal fluxes. Instead, these values are used to determine the relative potential of mine wastes as metal loading sources. Further, they cannot be used to estimate long-term leaching rates from mine wastes.

Some subsurface mine wastes are covered by non-acid generating materials (i.e. asphalt, soil) that reduce infiltration of surface water and subsequently reduce metal leaching from the mine wastes. Therefore, a correction factor was applied to account for the reduced infiltration due to the capping material. Asphalt covers, such as that found in the Concentrate Wharf area, were assumed to be only 90% effective in

reducing infiltration due to the presence of cracks in the cover that would allow some precipitation and runoff to enter. Soil covers (such as the Ball Field area) and exposed tailings with partial asphalt cover were assumed to be 80% effective. The Mill Building was assumed to be able to retard only 50% of the incipient precipitation. It should be noted that these estimates do not take into account the potential for groundwater flow through the mine wastes. Instead, these values can be applied to indicate the relative potential of various mine wastes as loading sources to Howe Sound.

Results of these calculations are shown graphically in Figure 4.4-2. Loadings from surface sources of mine waste account for approximately 43% of the metals loading to Howe Sound. Subsurface deposits contribute approximately 56% whereas loading from the Mill Building may represent less than 1% of the loading to Howe Sound. Concentrates represent the greatest source of loading, followed by copper launder sludges. Subsurface tailings deposits are also a large potential source of loading due to their large volumes. Waste rock deposits may contribute a considerable load in places where their volumes are significant, or their sulphide content is high due to the presence of ore-grade material, such as the slopes adjacent to the Mill Building. Due to their lower leachability, mixed mine wastes/fill are considered to be the least significant loading source.

Following completion of the Additional Areas DSI, the volumes and estimated loading from the Fan Area catchment should be updated to include the material in the Additional Areas within the Fan Area catchment.

4.5 Summary of Fan Area Contaminant Fate and Transport

Elevated metal concentrations in groundwater and surface water discharging from the Fan Area are the result of the interaction of inflowing waters with oxidizing mine wastes. Acid generation and metals leaching has likely been occurring at the Britannia site since the initiation of mining and mineral processing on the site. Although no predictive kinetic-testing based information is available, acid generation and metal leaching from the site will likely continue for hundreds, and potentially thousands, of years.

Sources of metal contamination in the Fan Area are found in five primary locations:

- **Mill Complex** consists of the present and historic locations of ore processing and surrounding areas where tailings were deposited and concentrate was stored, also including waste rock and low-grade ore stockpiles found on the slopes surrounding the Mill Building;
- **Concentrate Wharf Area,** located west of Highway 99, where tailings and waste rock were deposited as fill into Howe Sound, and various metallic concentrates were stored for shipment;
- **Sedimentation Pond** where sediment was removed from the 4100 Level mine discharge, and ore and launder sludges have been stored;
- **Settling Pond** where precipitates were removed from the copper launder overflow; and
- **Ball Field** area where pyrite concentrates were stored prior to shipment.

These locations contain both surface and subsurface deposits of mine wastes that can extend downwards below the groundwater or low tide elevations. Surface waters and groundwaters that interact with these

wastes become contaminated by metals, which can then flow to Howe Sound. The presence of a salt-water wedge likely restricts the groundwater discharge zone to the surface and shallow subsurface along the shoreline. Episodic stormwater events result in the discharge significant loads of dissolved metals and metals-contaminated sediment to Howe Sound. In general, metals concentrations in groundwaters and surface waters increase along their flowpath through the mine wastes.

The long-term time scale of the potential impacts are significant, and elevates the difficulty in finding suitable remedial measures that will stand the test of time. Therefore, permanent solutions that mitigate or eliminate the risk must be considered along with contaminant control and containment solutions.

5.0 REGULATORY REVIEW

The following documents comprise the regulatory context for the subject site:

BRITISH COLUMBIA:

- BC Waste Management Act
- BC Contaminated Sites Regulation
- BC Special Waste Regulation
- BC Mines Act and Regulations
- British Columbia Approved and Working Water Quality Guidelines; and
- Draft Criteria for Managing Contaminated Sediment in British Columbia

FEDERAL

- Canadian Environmental Protection Act
- Fisheries Act
- Metal Mining Liquid Effluent Regulation
- CCME Guidelines and Criteria

5.1 PROVINCIAL

5.1.1 Waste Management Act

The main environmental legislation in British Columbia is the Waste Management Act (WMA), providing a framework for waste disposal, permitting, contaminated sites management, special waste management, municipal waste management, waste ownership and liability and the appeal process. It also establishes responsibility and authority of provincial regulators, enables the passing of regulations and gives the legal definition of certain activities related to waste management, including the definition of pollution.

5.1.2 Contaminated Sites Regulation

The BCMWLAP has established standards for evaluating contamination and associated remediation requirements in the CSR (April 1997), the subsequent first amendment (July 1999) and second amendment (February 2002). The CSR and the Waste Management Act (1993) came into effect April 1, 1997. The CSR provides a framework to investigate, assess and remediate contaminated sites in British Columbia.

Soil standards are classified into five categories, based on the type of land use. Sites that contain analytical parameters at concentrations greater than the standard for the specific land use are considered to be contaminated. The land use types are as follows:

- AL - agricultural land use;
- PL - urban park;
- RL - residential land use;
- CL - commercial land use; and
- IL - industrial land use.

Under the CSR, there are three main approaches to the classification and remediation of soils. The Generic Numerical Standards refer to concentrations of given substances in soil or water for a particular land use. Matrix Numerical Standards are applied for some substances in soil, and are more specific than generic numerical standards, by providing standards for specific ecological and human receptor groups. Ecological and human health risk assessment is used to identify whether remediation to numeric standards is really necessary to safeguard receptors under the site's unique potential exposure scenarios, and/or determine whether prospective risk under various remediation scenarios (e.g. remediation of some media/areas to criteria, while leaving some media in excess of standards in place) is acceptable.

The Fan Area of the Britannia Mine site contains a variety of land uses that need to be considered. The predominant land use is considered to be commercial / industrial (CL/IL), resulting from the presence of mine related activities, the Mining Museum and several small restaurant facilities. In addition, there is limited residential (RL) use of the Fan Area. The Official Community Plan (OCP) broadly describes future redevelopment of the area, which does not preclude residential development of the Fan Area. Therefore, for the purposes of our remediation plan, URS has considered residential (RL) to be the most conservative applicable land use. Ecological and human health risk assessment and risk management are key components of the proposed remedial strategy and have been used to evaluate the suitability of various remedial approaches relative to environmental risk.

Water criteria are classified into five levels, based on the use of the water in the vicinity of the site. Sites at which parameters exceed the specific criteria for the type of water use at the property are considered contaminated. The water use types are as follows:

- AW - aquatic life;
- IW - irrigation;
- LW - livestock watering;
- DW - drinking water; and
- NW – no water use.

As the Fan Area is immediately adjacent to Britannia Creek and Howe Sound, the aquatic life (AW) standards for marine and fresh waters apply where contaminant concentration approaches are used. The Fan Area surface water and groundwater are not currently used for drinking water purposes although the risk assessments completed for the Fan Area did consider this potential use. However, since in general this water is not considered to be potable and use of Fan Area water for agricultural or recreational purposes is not expected in the long term, the other CSR water standards do not apply. Since the use of ecological and human health risk assessment are key components in the design of the proposed remedial

strategy, it is the concentration and loading of contaminants of concern in water discharges, and the subsequent reduction in environmental risk, that should govern the selection of remedial measures.

5.1.3 Special Waste Regulation

The Special Waste Regulation (SWR; 1988) classifies substances as Special Wastes if they contain leachable contaminants at concentrations in excess of a specified maximum. Special Wastes may also be defined by their total content of certain substances. Soil contaminated in excess of the Special Waste standard must be handled and disposed of as Special Wastes in accordance with the SWR.

5.1.4 British Columbia Approved and Working Water Quality Guidelines

BCMWLAP has developed approved and working water quality guidelines representative of chemical concentrations not to be exceeded to protect human health (drinking water) and aquatic biota (surface water). Both are presented in the British Columbia Approved Water Quality Guidelines (WQG; 1998 Edition, updated August 2001) and Working Water Quality Guidelines (WQG; 1998 Edition, updated August 2001). Both the freshwater aquatic life (FAW) guidelines and marine aquatic life (MAW) guidelines were applicable to this site.

5.1.5 Principles for Preparing Water Quality Objectives in British Columbia

Water quality objectives are criteria adapted to specific bodies of fresh, estuarine, and coastal marine surface waters as part of BCMWLAP's mandate to manage water quality. Objectives are derived from criteria by considering the local water quality, water uses, water movement, waste discharges, and socio-economic factors. Objectives have no legal standing due to the difficulty in accurately measuring contaminants in receiving waters and attributing to specific sources. However, to control diffuse sources of wastes (from groundwater seepage or surface runoff) waste management permits sometimes include receiving water ambient limits, which may be derived in part from water quality objectives.

Objectives do not apply within an initial dilution zone (IDZ), which is normally up to 100m from the point of discharge. Within an IDZ, water quality may exceed criteria but the discharge should not be acutely toxic within this zone. However, outside an IDZ, water quality should be suitable for all designated uses, and should protect aquatic life from sub-lethal effects, at a minimum.

5.1.6 Criteria for Managing Contaminated Sediment in British Columbia

Sediment criteria are presented in the BCMWLAP document entitled Draft Criteria for Managing Contaminated Sediment in British Columbia (BCMELP Draft; March 1999). These Level I and Level II criteria represent chemical concentrations permissible in near site sediments if criteria based remediation is used for a site. The Level 1 and Level II criteria represent conditions the Ministry deems acceptable, whereby possible biological effects are expected to be relatively absent (Level I) or minor (Level II). Sediment sampling results were compared with the BCMELP Draft Level I criteria. Although the Site is a former mine, the more stringent Level 1 criteria were used.

5.1.7 Mines Act

In British Columbia, mining is regulated under the *Mines Act* and the Health, Safety and Reclamation Code. Mine reclamation activities must be approved by obtaining a permit from the Chief Inspector of Mines under Section 10 of the *Mines Act*. This permit approves the reclamation program plus any other related activities on the site. Plans must be updated every five years or whenever significant changes occur. Permits issued under Section 10 contain conditions for acid rock drainage and metal leaching prediction and prevention, including conditions for excavation, waste deposition, waste characterization, reclamation, and the provision of financial security for outstanding reclamation liability.

5.2 FEDERAL

5.2.1 Canadian Environmental Protection Act

The Canadian Environmental Protection Act (CEPA) is a federal legislative framework designed to support sustainable development that is based on an ecologically efficient use of natural, social and economic resources and acknowledges the need to integrate environmental, economic and social factors in the making of all decisions by government and private entities. CEPA provides the legislative mandate for the Federal government to establish environmental standards, ecosystem objectives and environmental quality guidelines and codes of practice to be achieved and applied across Canada. CEPA contains a variety of contaminant tracking and reporting mechanisms for toxic substances and adopts the "polluter pays" principle, but generally lacks specific requirements for waste management permitting; this is left to the provinces to regulate.

5.2.2 Fisheries Act

The Fisheries Act governs commercial and recreational fishing and the protection of fish habitat in all waters (fresh, marine, or estuarine) in Canada. The parts of the Act most applicable to remedial activities at the Site and adjacent off-Site areas relate to the discharge of deleterious substances into fish-bearing waters (Howe Sound) and the alteration of fish habitat (Britannia Creek and/or Howe Sound).

5.2.3 Metal Mining Liquid Effluent Regulations

The Metal Mining Liquid Effluent Regulations (MMLER) address the discharge of liquid mine wastes to the environment subject to concentration limits for various heavy metals and pH limits. The regulation provides guidance on the nature of control work and environmental monitoring. The MMLER apply to new, expanded and reopened mines, therefore the MMLER does not appear to apply to the Britannia Mine.

5.2.4 CCME Guidelines and Criteria

The Canadian Council of Ministers of Environment has developed, and continues to update, numerical chemical concentrations for soil, sediment, surface water and tissue residues in the Canadian Environmental Quality Guidelines (CEQG). These are recommended as levels that should result in negligible risk to biota, their functions, or any interactions that are integral to sustaining the health of ecosystems and the designated resource uses they support. Environmental use guidelines for water

include drinking water, recreational water, aquatic life, irrigation water and livestock water. For soil, environmental land uses guidelines include agricultural, residential, parkland, commercial, and industrial. Sediment guidelines include marine and freshwater. CEQG has tissue residue guidelines for wildlife consumers of aquatic biota and air guidelines for human health, vegetation, animals, materials, and aesthetic atmospheric parameters.

The legislative authority for implementation of CEQG lies primarily with each Provincial jurisdiction, with the exception of Federal lands. Consequently, BCMWLAP has adopted most of the CCME values as its own environmental quality criteria and guidelines. URS used Provincial standards, criteria, and guidelines for the site assessment; however in some cases CEQG values were used, when Provincial values were not available.

6.0 SITE-SPECIFIC REMEDIATION OBJECTIVES

6.1 APPROACH

In development of the remedial plan, URS has also considered the potential presence of other remedial activities. These include the construction of a water treatment plan (WTP) for the mine water discharge, and the potential construction of an on-site disposal facility for sludges from the WTP. Treatment costs for contaminated groundwater or surface water are assumed to be borne by the WTP. URS also assumes that continued investigation of the Fan Area and Additional Areas may affect the development of a final remedial plan. Further, consultation with the stakeholders and the public will be part of the remedial plan process, and may impact the design and execution of the remedial activities.

6.1.1 Regulatory Framework

The Contaminated Sites Regulation provides guidance on remediation planning and implementation. However, the Britannia Fan Area is unlike most contaminated properties typically envisioned by the CSR; the area and volume of contaminated sources are very large, the impacts to the receiving environment can be considered to be a combination of non-point sources (groundwater) and point sources (surface runoff and deposits of mine wastes), the risk and impact on the receiving environment is large, and the duration of the risk is essentially indefinite if left unchecked. Therefore, remediation of the Fan Area is more similar to a mine reclamation project than a typical contaminated industrial site remediation project. In this regard, spatially large solutions dealing with non-point source impacts have been considered along with more standard contaminated site approaches.

The development of remediation objectives for the Fan Area is consistent with BCMWLAP's 'Principles for Preparing Water Quality Objectives in British Columbia' (1986). BCMWLAP indicates that water quality objectives may be used, in part, to derive ambient limits to control diffuse sources of wastes (from groundwater seepage or surface runoff), and that water quality objectives can be applied to specific locations, taking local circumstances into account. In the sense that the toxicological reference values (TRVs) derived for the Fan Area are species- and site-specific, the use of these TRVs as numerical values for the purpose of designing and implementing a risk management strategy at Britannia is consistent with the principles of developing water quality objectives.

Further, it is stated that water quality objectives do not apply within an initial dilution zone (IDZ), which is the initial portion of the larger effluent mixing zone. IDZ's are described as *"normally relatively small (e.g., up to 100m from the point of effluent discharge, but not exceeding 25 to 50% of the width of the waterbody)"*, and further that, *"within initial dilution zones... sub-lethal effects on aquatic life may occur"*.

BCMWLAP's Guidance on Ecological Risk Assessment (1998) is consistent with the above, stating that *"For environmental receptors... the goal is not to protect each individual from any toxic effect, but rather to protect enough individuals so that a viable population or community of organisms can be maintained."*

In developing remedial options for the Fan Area, URS' objective was to ensure that the preferred option would be protective of site-specific populations and communities. To this end a conservative IDZ of only 5 metres for groundwater discharging from the Fan Area into Howe Sound was applied, 20 times smaller than a 'typical' IDZ. It is considered that this small IDZ will ensure that individual toxic effects would be minimised, resulting in the maintenance of viable populations and communities.

6.1.2 Assimilative Capacity of the Receiving Environment

COC flux is expected to be assimilated relatively rapidly due to mixing in the near-shore receiving environment. Mixing of COC flux (via groundwater seepage) with surface water is expected to result primarily from the interaction of shallow, near-shore currents with this flux. Shallow currents were measured through a previous study to be approximately 0.14 meter per second (m/sec; average absolute value) (Buckley, 1977) in the Britannia Beach area. The predominant current direction was found to be northerly.

Maximum COC concentrations in the receiving environment will result under conditions of low tide (when the groundwater flow gradient is highest) and low current (when mixing of groundwater discharge is lowest). Minimum COC concentrations will result during high tide conditions (when the groundwater flow gradient is directed inland), and/or when there are high currents.

Using a simple mixing model, COC fluxes in the North and South Fan Areas were estimated for the present condition, and under several different remediation scenarios. Since predicted COC flux is greatest in the South Fan area, the emphasis in terms of establishing remediation objectives was focussed in this area.

Based on copper and zinc of 10,000 and 16,000 g/day, respectively, the mixing model predicted resultant copper and zinc concentrations of 17 and 27 µg/l at a distance of 5 metres from the groundwater discharge boundary. According to the model, reductions in copper and zinc fluxes will have a directly proportional effect on concentrations in the receiving environment (i.e., 50% reduction in flux will result in 50% reduction in concentration at 5m from the discharge boundary).

Appendix C contains a description of the mixing model used to predict COC concentrations in the receiving environment.

6.1.3 Remediation / Risk Management Objectives

With the previous rationale for the development of water quality objectives for the Fan Area and preliminary dispersion and mixing modelling, the following governing risk management objective for the Fan Area is proposed:

> ***Increase habitable areas in the aquatic environment by reducing the discharge of toxic constituents in a cost effective manner.***

Implicit to this risk management objective are two concessions:

- Limited habitat areas will remain that can not be totally restored to past functions and services, e.g. limited areas of intertidal and shallow subtidal habitat for sessile benthos; and,

- In considering the appropriateness of remedial measures, the concept of incremental benefit for each dollar spent on remedy is important, i.e. marginal benefit for each dollar spent is an important remedial decision criterion.

Since none of the contaminants of concern are bioaccumulative, there are no risks to higher trophic levels such that even under the present condition, impacts to wildlife through food chain transfer are not expected. However, to protect enough individuals to maintain a viable population or community of aquatic organisms in Howe Sound in the vicinity of the Fan Area, it is proposed that a water quality objective that is protective of the most sensitive species be met within a 5 metres distance of the groundwater discharge interface. The Tier 1 ecological risk assessment for the site found that phytoplankton were the most sensitive (to copper), with a chronic TRV of 4 µg/l.

Based on the foregoing, URS proposes that a remedial option (or combination of options) be implemented that results in reducing the flux of copper such that the concentration of copper at 5 metres from the groundwater discharge interface of the Fan Area is less than 4 µg/l. Since zinc is less toxic to the receptors of concern, measures to reduce copper flux to the proposed level would be sufficient to address zinc in surface water also.

For example, based on our estimates of copper and zinc flux from the South Fan Area and the mixing model, we believe that a 77% reduction in the present flux of contaminants of concern would be necessary to achieve this objective. A flux reduction of this magnitude would result in a reduction of both copper and zinc to below chronic TRVs for the most sensitive receptors of concern at 5 metres from the groundwater discharge interface. This reduction in flux can be achieved through a reduction in the concentration of the contaminants of concern in the discharge from the Fan Area, by a reduction in the volume of discharge from the Fan Area, or a combination of both.

Caution needs to be exercised in the translation of the aquatic objective to an upland objective. There are a number of sources currently affecting the environmental status of the intertidal and subtidal area of Howe Sound immediately adjacent to the Fan Area, such as the mine waste discharge, stormwater and groundwater, and the proportion of impacts from each of these individual sources is not well understood at this time. Similarly, the positive impact of implementing mitigative measures on individual sources is also difficult to quantify exactly. Therefore, a performance-based approach to implementing risk management is recommended. This will permit the risk management and remediation activities to be monitored and the progress towards achieving the receiving environment risk management objectives to be determined.

7.0 REVIEW OFR EMEDIATION ALTERNATIVES

7.1 INTRODUCTION

This section of the remediation plan provides an overview of various remedial measures that have been considered for the Fan Area. URS has organized the options revie w according to a risk-based remediation approach; the three components of an environmental risk model are the contaminant source (where and how the potential risks are caused), receptors (humans, plants and animals that may reside in the area and be exposed to contaminants of concern), and the pathway of exposure (the mechanism conveying the contaminant from the source to the receptor).

URS has assumed that the receptors (either actually present or theoretically present if conditions were appropriate) are desirable and necessary, and therefore we have not considered control mechanisms related directly to control of the receptors. Therefore, remedial measures evaluated and proposed by URS centre around controlling source areas (contamination prevention) and controlling the exposure pathways (transport control). The objective of the remediation pian is to reduce risk to the receiving environment in an expedient, but also practical and cost effective, manner that is acceptable to BCMWLAP and the Britannia technical and community stakeholders.

7.2 CONDITIONS AND ASSUMPTIONS

The following conditions and assumptions were used for the formulation of remedial options for the Fan Area:

- A water treatment plant (WTP) will be in operation by April 2004. The WTP will have a normative capacity to treat 120 m^3/hr (2880 m^3/day) of groundwater.
- No allowance in the WTP design has been made for stormwater treatment.
- Cost of construction of the WTP is excluded from this remedial plan.
- On-site disposal costs of mine wastes and WTP sludges do not include upgrades to existing roads or construction costs for new roads.
- Assessment and clean up of the Mill Building are not part of this remediation plan.
- Remediation planning for petroleum hydrocarbons, presently identified at a PSI level, is not included in this plan.
- Site land-use designations will not change as a result of the remedial activities.
- Aesthetic improvements to the site are not included in this plan.
- Costs for remedial activities were calculated based on estimated capital costs plus present-day operational and maintenance costs. These costs were obtained from qualified contractors or, where not available, were based on professional judgement.
- Present value (PV) costs for remedial activities requiring long-term operation and maintenance (O&M) were estimated by calculating the present day annual O&M cost and multiplying by 20.

7.3 SOURCE CONTROL

Source control involves minimizing the generation of contamination as close as possible to the source area. At the Britannia Fan Area, feasible source control measures include removal of contaminated soils and sediments to reduce or eliminate the potential for impacts, or the isolation of contaminated soil and sediments to protect surface water and groundwater from contamination. Due to the high acid generation and metal leaching potential of the mine wastes, the in-situ treatment / stabilization of the site soils to reduce risk was not considered feasible.

7.3.1 "As is" Approach

The 'as-is' approach to source control involves accepting the current site status as-is, and focussing the remedial efforts on minimizing environmental risk via exposure pathway control only. While URS believes this is not a desirable option as a primary remediation strategy, we have evaluated it for comparison to the other approaches evaluated.

With respect to human health risks posed by contaminated soils, sediments and materials in the Fan Area, the as-is approach would be generally acceptable. The URS human health risk assessments indicate relatively low human health risk resulting from the presence of contaminated material on a day-to-day basis, and requires relatively basic personal protective measures for workers who may be exposed to contaminated materials during construction that involves soil disturbance. This approach would also preclude any use of Fan Area groundwater for any productive use, such as potable water supply or irrigation.

With respect to ecological risks, the URS Tier I risk assessment identified several terrestrial receptors of concern that are being impacted by contaminated soils and sediments, such as plants, soil invertebrates and robins. Given current and potential future land use of the Fan Area as commercial and industrial land use, these receptors are unlikely to be found in significant numbers in any event.

With respect to aquatic receptors, the Tier I risk assessment identified an unacceptable level of risk to a number of receptors. The as-is approach to source control will require mitigative measures to be implemented on exposure pathways so that the risk posed by the Fan Area to these receptors will be controlled.

In summary, the as-is approach used exclusively in the Fan Area is not acceptable to the receiving environment, and may only be used for selected portions of the site in conjunction with other mitigative and risk management measures designed to control exposure pathway (transport control via groundwater and surface water containment and treatment).

7.3.2 Capping

Capping can be used to restrict the access of water and oxygen to mine wastes. Restricting the flow of water and oxygen will reduce the rate of sulphide oxidation and metal leaching/transport from the wastes. Capping materials must have a low permeability to oxygen and/or water and not be subject to cracking, erosion or punctures that could increase the permeability. A wide variety of materials and methods can be

used to cap mine wastes. At mine sites in British Columbia, water covers are a preferred capping method for reactive mine wastes to limit oxygen and to significantly reduce sulphide oxidation. However, water covers can result in the release of soluble metals during inundation. Dry covers or saturated soils can also be employed to limit oxygen diffusion. These covers tend to be thick (1-3 m) and expensive to construct. Limiting water infiltration can be achieved using a variety of types of soil covers, geotextile (synthetic) materials and other materials such as asphalt or concrete. Effective application of a particular capping method is dependent upon many factors, including cost, and is generally site-specific.

Control of oxygen diffusion will require either a water cover, or a more complex and expensive dry/saturated cover. A water cover would require the construction of a water impoundment structure in parts of the Fan that would likely result in the release of large quantities of soluble metals once flooded. A suitable dry or saturated cover would require the excavation of 1-3 meters of existing materials in order to maintain the present site grade.

A cover of 1-3 meters is equivalent to the approximate thickness of mine wastes above the water table; therefore, there would be no advantage in its use versus removal of the source down to the water table. Also, the cover would have to be constructed to ensure that oxygen could not migrate inwards from its perimeter. Construction of a continuous oxygen-limiting cap over the mine wastes is encumbered by the presence of numerous buildings in the Mill Complex area. These would likely have to be removed during construction.

For the Britannia Fan Area, URS believes that utilizing capping methods to control infiltration will be more effective than attempting to control oxygen diffusion as a means of minimizing Fan Area impacts to Howe Sound. Decreasing infiltration will reduce the volume of water leaching the mine wastes above the water table and will reduce the volume of contaminated groundwater that will have to be controlled and contained.

The most effective capping materials for this site are:

- Asphalt
- Synthetic liners
- Soil Covers
- Shotcrete

While synthetic liners have lower liquid permeability than asphalt, both have low air permeability. Asphalt is better suited to load bearing requirements and more resistant to weathering than geotextiles. Overall thickness of these covers is variable, but likely is between 20-40 cm for asphalt (with a gravel sub-base), and up to 10 cm for multi-layer synthetics. The cost of asphalt caps for the Fan Area is approximately up to \$19 per m^2, as reviewed in Table 7.2-1. The cost of a synthetic cap is approximately \$10/m^2, as reviewed in Table 7.2-2.

Soil covers could also be utilized but in general have to be a metre or more in thickness in order to meet the oxygen limiting requirements, requiring the excavation of several metres of existing soils/wastes in order to maintain grade elevation. Soil covers are also generally less effective at reducing water

infiltration than asphalt or synthetics. Shotcrete can also be employed in locations such as slopes where other capping techniques would be difficult and load bearing is not required.

URS recommends the use of asphalt as a capping material on horizontal surfaces in the Fan Area to reduce water and oxygen infiltration. Asphalt requires periodic maintenance to retain its low permeability, but has the durability and load bearing capacity required for the operational demands of the site, notably vehicular and pedestrian traffic related to the tourist and light commercial/industrial activities in the Fan Area. Potential areas for capping are shown in Figure 7.2-1.

For horizontal areas without load bearing requirements and where reclamation and revegetation would be desirable, a synthetic cap with soil cover suitable for plant growth would be the most cost effective approach. There are limited areas within the Fan Area that would qualify for this remedial method.

URS evaluated the application of a shotcrete cap on both horizontal and vertical surfaces as a means of controlling contamination at source (see Table 7.2-3). Shotcrete is a suitable option for sloped or vertical surfaces where other capping methods would not be applicable. The shotcrete cap has been evaluated assuming the incorporation of reinforcing steel and corrosion resistant anchors, plus geosynthetic underliners on sloped surfaces, as part of the design of a permanent structure. However, as illustrated in the table, shotcrete has a high unit cost (over $40 per m^2) and is cost prohibitive considering the large areas that would be suitable for capping.

7.3.3 Source Removal

Source removal can be used to eliminate the contaminant source and reduce the loading from the material to the exposure pathway route. Source removal involves excavation of the contaminant and transport to a location where its impacts to the surrounding environment are negligible. Excavated contaminated material will likely require soil treatment, encapsulation or water treatment of its leachates to minimize impacts on the environment.

A range of options exists for source removal, from selective removal of high metal load sources to complete removal of all sources. In most locations, excavated areas would be replaced with clean fill. The fill would be capped where necessary to prevent downgradient impacts from infiltrating water.

Disposal locations for the excavated material still have to be determined. In order for source removal to be a practical solution, on-site disposal will be mandatory, if excessive transportation and tipping fees are to be avoided. Possible on-site locations include the Jane Basin, or elsewhere on the Britannia Mine property, such as the Mount Sheer area. Storage of uncovered mine wastes in the Jane Basin would permit leachates to flow into the mine workings where they would eventually be treated by the WTP. The wastes could be encapsulated to reduce or eliminate these discharges. Disposal outside of Jane Basin (e.g. the Mount Sheer area) would require the construction of a capped impoundment to encapsulate the wastes to minimize oxidation and leaching. Depending upon the volume of excavated material, disposal (encapsulation) of the mine wastes within an on-site WTP sludge containment facility may offer a cost saving and additional benefit of partial neutralization of the mine waste by excess lime in the sludge.

If no on-site disposal options are possible, off-site locations may be required. The soils are likely suitable for disposal at contaminated soils repositories in Alberta. Disposal in a constructed impoundment or open pit at another mine site is another possibility. However, costs for transportation and tipping at an off-site non-hazardous waste disposal facility are likely prohibitive. Costs for transportation and tipping at an off-site non-hazardous waste disposal facility typically range from $130/m^3$ ($65/tonne) for rail transport, to $240/m^3$ ($120/tonne) with truck transport, and can be several hundred dollars per cubic metre if pre-treatment / stabilization of the waste is required. Off-site transportation costs alone range from at least $40/m^3$ ($20/tonne) for bulk rail volumes to over $160/m^3$ ($80/tonne) for smaller truck volumes.

Depending upon the type of mine waste and the concentration of metals therein, some cost recovery may be obtained through reprocessing. Results from the DSI indicate that gold concentrations over 1g/t are present in over 10% of the soils, with concentrations up to 100g/t observed in the concentrates. Some of these materials could potentially be sold to recoup remediation costs or exchanged to a third party in return for their removal from the site.

URS has identified key areas where source removal would provide both a reduction in terrestrial ecological risk and aquatic risk to Howe Sound. Surface deposits of concentrates, launder sludges and waste rock/ore materials have been identified (see Section 4.4) as significant loading sources to groundwater and surface water. Episodic stormwater discharges result in the leaching of significant quantities of metals from these locations. They are also areas of very high Hazard Quotients (HQ) for terrestrial fauna. Subsurface deposits of concentrate, tailings and waste rock are also significant loading sources to groundwater flow that impacts the Howe Sound receiving environment.

Contaminated materials above the groundwater table (both seasonal low and high water table) are believed to be larger contributors than permanently saturated contaminated materials below the water table. Removal of these unsaturated materials has a significantly greater cost benefit than the saturated materials and therefore are strong candidates for selective excavation.

Estimated excavation costs are presented in Table 7.2-4. The cost for excavation varies depending on the degree of difficulty, need for dewatering, and depth of excavation. We are assuming relatively simple surficial excavation above the seasonal low water table (or tidally influenced water table) at a rate of approximately $4/m^3$. For sloped surfaces, such as those adjacent to the Mill Building, a non-standard excavation approach would have to be used. It is possible removal by hand with limited mechanical assistance would be feasible; alternatively, construction of benches in the bedrock slope to permit excavator access may be required. Removal costs for these approaches could range from $6/m^3$ up to $12/m^3$. Washing the east and west slopes adjacent to the Mill Building is not considered a viable option as this remedial option would result in a large volume of wash water that would require costly treatment.

On-site haulage costs have been estimated at $13/m^3$. This cost was based on transporting the material to Jane Basin, likely the furthest on-site distance that waste would be hauled. Disposal of the materials in a geotextile and soil capped impoundment were estimated at $5/m^3$, not including annual maintenance costs. Costs for road upgrades to the Mount Shear / Jane Basin to permit the required truck haulage were not estimated by URS, but could approach $100,000 per kilometre.

7.4 EXPOSURE PATHWAY CONTROL

Exposure pathway is defined as surface runoff, groundwater and surface waters which have been directly impacted by contaminants from the solids, or are transporting contamination originating in another area. Exposure pathway control accepts that impacts to surface water and groundwater have occurred, making installation of control works necessary, likely with collection and treatment. Control of inflowing water sources to contaminated areas to restrict flow volumes along the exposure pathway has also been included in this discussion. Capping contaminated materials is also a method of reducing influent water volumes and has been discussed under Section 7.2.

7.4.1 "As is" Approach

The "As-is" approach to exposure pathway control involves carrying out no modifications to the water flowpaths, volumes or quality. Instead other methods, such as source control (contaminant removal), would be utilized to reduce risk or impacts. This approach also includes rehabilitation of other areas (habitat compensation).

Utilization of this approach would require significant removal of mine waste (contaminant) sources in the Fan Area to reduce impacts to the receiving environment. Attenuation of risk along the exposure pathway to acceptable levels would be dependent upon the degree of source removal and could take an unacceptable period of time (10's to 1000's of years) to achieve.

In summary, the as-is approach used exclusively in the Fan Area is not acceptable to the receiving environment, and may only be used for selected portions of the site in conjunction with other mitigative and risk management measures that prevent or eliminate the generation of impacted storm water and groundwater.

7.4.2 Surface Water Diversions and Stormwater Collection

Prevention of water contamination by limiting the volume of inflowing water is a method of exposure pathway control. Surface water diversions can be used to prevent clean water from contacting contaminated soils. Approximately 75% of the water entering the Fan Area from the upgradient catchment may be in the form of surface water and shallow groundwater flows. These waters flow through the mine wastes and transport dissolved (or particulate) metals to Howe Sound in groundwater and surface water. Stormwater collection can be used to direct precipitation or uncontaminated runoff to drainage systems and thereby reduce interaction with contaminated surface materials and infiltration to groundwater. Stormwater collection is most effective when used in conjunction with a capping material to reduce or prevent infiltration.

URS proposes that diversion ditches be constructed upgradient of the Fan Area to intercept surface water flows and prevent them from entering the Fan Area. A series of open ditches located at the 4100 level and at the base of the Fan Area slope would be used to collect surface runoff. Clean water would be diverted directly to Britannia Creek or to Howe Sound. Potentially contaminated runoff from the Mill Building area and adjacent slopes would be collected and piped to the WTP. Proposed locations for these diversions are shown in Figure 7.2-1.

Stormwater collection on capped areas of the Fan would also be required. Surface flows on the capped areas would be directed to a series of catchbasins and then by pipe to Howe Sound. Oil interceptors (stormceptors) could be utilized in high traffic and parking areas to prevent uncontrolled hydrocarbon discharge to Howe Sound.

URS estimates that construction of diversions capable of intercepting 50% of the upgradient surface water flow plus the emplacement of an asphalt cap over most of the south Fan Area could reduce groundwater discharge to one-third of its present flow (Figure 7.3-1a). Contaminated surface water runoff from the south Fan would be reduced by 90%. Construction of similar diversions in the north Fan plus an asphalt cap over areas adjacent to the Ball Field could reduce groundwater flows by approximately 40% and potentially contaminated surface water runoff by approximately one-half (Figure 7.3-1b). In addition, the volume of mine waste derived suspended sediment in stormwater would be reduced significantly, potentially resulting in a decrease in the amount of contaminated sediment in the intertidal zone.

Optimization of surface water diversions and stormwater collection will require definitive evaluation of existing stormwater pathways, in conjunction with Fan Area catchment water balance, to determine appropriate routes and sizes. Estimated costs for diversion ditches and stormwater collection are presented in Tables 7.3-1 and 7.3-2.

7.4.3 Groundwater Control

In the absence of any other remedial measures, groundwater control would be necessary to reduce risks to ecological receptors in Howe Sound. In this case, groundwater control will have to be a long-term (permanent) strategy if upgradient sources continue to generate impacted groundwater. However, when other remedial measures (e.g. source removal, diversions, capping) are implemented, groundwater control may be unnecessary or only be required as a short-term strategy to address existing impacted groundwater that will eventually improve with source removal.

The optimal groundwater control strategy will depend on which of the other complementary risk reduction strategies, such as source control, capping, diversions and stormwater control are selected. Ultimately, the objective is to reduce the risk to Howe Sound, and therefore the design effectiveness of the groundwater control and containment system will depend on the degree to which this system will be required to reduce risk. Timing for implementation is also a factor in the design; the WTP will not be commissioned until April 2004, and therefore a control and containment measure involving groundwater extraction can not be implemented until that time.

A groundwater control and containment system (GCCS) requires the use of multiple extraction wells, potentially in conjunction with a barrier wall. The various GCCS options are discussed below.

7.4.3.1 Pump and treat

South Fan

Pump and treat as a stand-alone remedy (i.e., without any complementary source control measures) would likely require full hydraulic containment of the south Fan. Scenarios involving full hydraulic containment of the south Fan were simulated using Modflow, and optimized by assessing which scenario resulted in

maintaining hydraulic containment at the lowest overall pumping rate. Scenarios involving partial containment were also simulated. Such scenarios could be acceptable if implemented in conjunction with source control measures. Partial containment scenarios were optimized by assessing which scenario was able to achieve an approximate 50% reduction in metals flux to Howe Sound at the lowest overall pumping rate.

Model results indicate that full hydraulic containment of the south Fan could be achieved at a combined pumping rate of 1300 m^3/d from 4 extraction wells situated near the Fan's boundary with Howe Sound. The current estimated metals flux to Howe Sound from the south Fan would be reduced by 100% under this scenario.

An approximately 50% reduction in metals flux to Howe Sound could be achieved under a partial containment scenario that focussed on hydraulic containment of the more heavily impacted areas of the South Fan. The model predicts that a combined pumping rate of 545 m^3/d from 2 extraction wells would be required under this scenario.

North Fan

In the north Fan area, pump and treat may be required if it was applied as a stand-alone remedy. As for the south Fan, full and partial containment scenarios were simulated for scoping purposes.

The model indicates that a full containment scenario would require pumping from three (3) extraction wells at a combined rate of 750 m^3/d. A partial containment (50% reduction in metals flux) option would require pumping from 2 extraction wells at a combined rate of 350 m^3/d. Costs for these options are given in Table 7.3-3.

7.4.3.2 Pump and treat with barrier wall

Advantages offered through the installation of physical barriers to groundwater flow were assessed through numerical modelling (Modflow). Potential advantages were thought to include:

- A reduction in the groundwater flow gradient in areas of the fan where metal concentrations are greatest, thus reducing metals flux to Howe Sound; and
- Reducing the proportion of seawater in the extracted groundwater.

URS considers that generation of high salinity groundwater as part of a pump and treat strategy will be inevitable due to upconing of the saline wedge beneath the fan. Since a down-gradient barrier wall would not likely significantly mitigate this upconing phenomenon, this option (as a means of reducing the salinity of extracted groundwater) was not given serious consideration.

A barrier wall upgradient of source material was seen as potentially advantageous due to the gradient reduction, and consequent groundwater flux reduction, that could be achieved through this source zone. Although the gradient (and hence groundwater flux) would decrease in the source area, the gradient and groundwater flux would increase in other areas, mainly around the edges of the barrier wall. If these increases could be engineered to occur through areas of the fan that were not significant sources, an overall reduction in metals flux could be realised, resulting in a lower groundwater extraction

requirement. Pump and treat with barrier wall options were simulated using Modflow. Full containment scenarios were simulated for the South Fan area only.

Modelling indicates that a 10% reduction in metals flux to Howe Sound from the south Fan could be achieved using a 100m long by 23m deep barrier wall situated up-gradient of the main source area (i.e. Concentrate Wharf). A 50% reduction in metals flux can be achieved by pumping one well between the wall and the shoreline at approximately 400 m^3/day. This does not result in a significant improvement over the pump and treat with no barrier wall option. Due to the high cost of installing a physical barrier and the limited benefits offered in terms of reducing the volume of groundwater requiring treatment, this option was not given serious consideration. The cost of pump and treat with barrier options is given in Table 7.3-3.

7.4.3.3 Permeable Reactive Barrier Wall

A permeable reactive barrier is constructed of a porous material that is selected for its ability to change the chemical composition of the groundwater to one that is less toxic to the receiving environment. In principle, impacted groundwater flows through the barrier, and in the process the COCs are chemically removed or altered by the barrier wall material. Generally, these barriers are constructed by slurry wall or injection techniques. The composition and thickness of the barrier depends on the nature of the contaminants and the desired chemical effect to reduce risk. As the barrier functions, the effectiveness of the reaction is diminished, to a point where after perhaps a decade it would have to be completely replaced. Depending on these parameters, a reactive barrier for the Fan Area has been estimated to cost (installed) from \$600/m^2 to over \$1,200/m^2.

Reactive barrier technology is relatively new and not proven for an application such as Britannia. As a stand-alone option, a permeable reactive barrier would have to increase groundwater pH and reduce the concentration of copper and zinc before discharge to the receiving environment. In order to be optimally effective, the barrier would have to be situated close to the foreshore, and therefore would be subject to effects from salt-water intrusion. Precipitation of metals in and around the barrier is also a concern; precipitation of the COCs is likely to result in reduced hydraulic conductivity, thereby causing impacted groundwater to flow around the barrier instead of through it.

At this time, the most promising use of a permeable reactive barrier would be as a polishing, or final stage, of groundwater treatment prior to discharge to Howe Sound. As discussed above, other options appear feasible to remove or control sources so that groundwater quality may improve with time. For options where the need for groundwater control and containment may one day be eliminated, a permeable reactive barrier wall would provide the level of treatment required for that finite time period. However, in comparison other GWCC methods, a permeable reactive barrier would not appear to be cost competitive nor is the exact barrier material known in time to meet the demands of this project.

7.5 Material Management During Construction

The DSI identified various areas around the Fan Area that have contaminated materials present. As noted in the DSI, the investigation was not exhaustive and evaluated materials that posed the highest potential for environmental risk (generally materials above the water table), and was conducted without URS's

knowledge of potential future development or other infrastructure construction that may occur at the site. It is possible that redevelopment or construction activities may occur in areas where impacted materials may be present or may potentially be present. Of concern would be the risk to workers exposed to these materials (such as concentrates with elevated metals and potentially low pH) during construction activities that disturb these materials, impacts on the infrastructure materials (cables, steel piping or pilings, and to concrete), and the impact on construction costs resulting from the management and disposal of these materials or the implementation of protective measures for the infrastructure.

It is beyond the scope of this remediation plan to consider these eventualities, other than to highlight the need for consultation between the design professionals during the planning phases of these projects to ensure that material management impacts are considered. Of particular importance are the following:

- Worker health and safety: The risk to worker health and safety resulting from exposure to impacted materials and workplace accidents must be addressed through the preparation of a site specific health and safety plan, worker training in risk reduction and avoidance, and the provision of appropriate personal protective equipment.
- Identification and classification of materials: Where it is believed that contaminated material will be exposed, excavated or handled, it will be necessary to fully understand the nature of the contaminant risk and management options through proper identification and classification. As bulk excavation is anticipated to be the typical excavation approach, in-situ testing should be completed in suspect areas where excavation for infrastructure construction is to occur, or stockpile testing conducted to characterize the material prior to determining the disposal location.
- Interaction with infrastructure: Facility designers need to consider the nature of the materials contacting the facilities so that appropriate protective measures can be incorporated into the design. Site soil, mine wastes, groundwater, surface water and mine water are highly corrosive and will significantly reduce the lifespan of facilities and equipment if precautions are not taken.

8.0 PREFERRED REMEDIATION OPTIONS

8.1 REMEDIATION OPTION DECISION MATRIX

URS has presented several remedial options for the Fan Area. However, there are a number of constraints and opportunities that will affect the final selection of the Britannia Fan Area remedial strategy. Some of these constraints and opportunities that should be considered are:

- Permanence of Solution: Permanence of risk reduction is a fundamental principle of environmental protection in British Columbia. URS believes that where permanent solutions for contaminant sources are competitive in terms of cost and effectiveness to solutions that provide only control and containment (preventive solutions), then the permanent solution should be selected. The permanent solution may be more expensive in terms of net present value than the preventive solution, but this can be misleading. Leaving contamination in-situ will require long term monitoring to ensure impacts have been mitigated. As source areas remain, they will still pose a risk to the environment that would occur in the event of a system failure.
- Mitigative Timeframe: Contaminants in the Britannia Fan Area will continue to generate impacts to surface water and groundwater for decades and likely centuries to come, unless mitigated by permanent or preventive solutions. This is a major engineering constraint to the project. It is difficult to engineer solutions and infrastructure that will function forever as designed.
- Fan Area Redevelopment: A variety of redevelopment and land use options are being discussed for the Fan Area. Increased commercial development, potential residential development, a debris basin for Britannia Creek, and a new highway alignment somewhere near the 4100 level are all proposed. Redevelopment provides a significant opportunity to incorporate risk minimization options proposed by the remedial plan into the designs. For example, a new highway alignment could include upslope and upgradient water diversion features that complement remedial activities in the Fan Area. Increased parking areas for the museum and other commercial ventures can incorporate surface capping (pavement) with stormwater collection to complement the GWCC initiatives.

URS has developed a list of potential remedial activities for risk reduction from groundwaters, surface waters and soils in the Fan Area. These activities are considered the best available and practical techniques for reducing terrestrial and marine impacts from the Fan Area. URS recognises that external variables such as other remedial activities (eg. WTP, sludge disposal and debris hazard mitigation) may influence the scope or type of remedial actions. Also, additional data collected on the Fan or Additional Areas conditions may influence the type or extent of proposed remedial activities. Importantly, stakeholder and public requirements for remediation are expected to influence the final design.

Remediation options for the Fan Area have been subdivided into four catagories:

- **Diversions and Capping** – methods to reduce the volume of inflowing surface water (runoff and precipitation) from interacting with the Fan Area mine wastes.
- **Source Removal** – excavation and removal of mine wastes to eliminate their potential as contaminant load sources to surface water and groundwater.

- **Groundwater Containment and Control Systems** – methods to capture contaminated groundwater for treatment in the WTP.
- **Combined Remediation Activities** – optimal combinations of the above methods to achieve the desired levels of risk reduction.

Captial costs and present value (PV) costs were estimated for feasible remedial activitites. Risk reduction for each remedial alternative was estimated based on calculated potential reductions in metal loading to Howe Sound.

Tables 8.1-1 and 8.1-2 present comparisons of potential remedial options for the south Fan and north Fan respectively. Assessments have been made for qualitiative variables such as:

- Probability of Success
- Public/Stakeholder Acceptance
- Risk Reduction
- Duration to Install
- Independence from Constraints, and
- Operation and Mainatenence Effort.

Quantitative assessments were made for captial costs and PV O&M costs. These values were compiled from cost tables listed in Section 6.0. Estimates of metal load reduction to Howe Sound were made for each remedial option and are presented in Table 8.1-1. For those remedial options that do not achieve complete (100%) reduction in metals loading to Howe Sound, a cost estimate was developed for an add-on groundwater pumping system capable of intercepting all remaining contaminated groundwater. In addition, the estimated water treatment and sludge disposal costs from treated groundwater were also included, based on ongoing studies by AMEC. The PV cost of treating 100% of the groundwater is estimated at $3.5 million. Based on the Fan Area groundwater modelling and water balance, costs for water treatment were apportioned between the south (75%) and north (25%) areas. All costing for remedial options involving groundwater containment and treatment included a weighted value for treatment and sludge disposal. Reduced loads of contaminated groundwater due to the various remedial options were assumed to result in a comparable cost reduction in treatment and disposal. However, it should be noted that results of the Tier II risk assessment may allow higher discharge water quality and, depending upon the remedial option, may eliminate the requirement for an add-on groundwater collection system. Further, refinements to our understanding of the groundwater regieme may result in significant reductions to the required volumes and fluxes of groundwater that require pumping and treatment.

In the south Fan, costs for the proposed remedial options vary from $218,000 (surface diversions) to approximately $8.4 million (pump and treat with barrier wall). The ability of each remedial option to reduce metal loading to Howe Sound generally increases with increased cost. The groundwater capture and Complete Source Removal options are assumed to be 100% effective at reducing loading to Howe Sound. Some temporary groundwater pumping and treatment could be required for the Complete Source Removal option as any remaining contaminated groundwater naturally attenuates through mixing with recharge water and discharge to Howe Sound. Most of the options have an O&M component; the

exceptions are the Source Removal alternatives that are capital costs only and do not require ongoing maintenance costs.

Groundwater pumping options have the highest O&M costs due to the upkeep and maintenance of the pumping wells and related infrastructure. Figure 8.1-1 graphically compares the estimated cost versus calculated groundwater metal load reduction for remedial options in the south Fan. The various options span a wide range of costs and load reduction capabilities.

The remedial options were further assessed by estimating the cost of groundwater collection and treatment, and disposal of sludge resulting from contaminated groundwater not eliminated by each option. This allows for estimation of remedial costs if groundwater control and treatment was found to be necessary following installation of a more passive remedial option (e.g. source removal, capping, diversions or combinations thereof). Costs for these options are also shown in Table 8.1-1 and are presented in Figure 8.1-2. Potential costs for an add-on groundwater collection system vary, and are primarily dependent upon the water treatment and sludge disposal costs for the varying quantities of groundwater flow and concentration.

Remediation options for the north Fan are presented in Table 8.1-2. The options range in cost from $60,000 (surface diversions) to $3.7 million (pump and treat). In general, estimated reductions by the lower-cost remedial options (diversions, capping, surface source removal) are less than those for the south Fan. This is a function of the more limited extent of contamination in the north Fan area, which is primarily focussed in the subsurface Ball Field area and the surficial deposits of the copper launder settling pond.

Costs for the installation of an add-on groundwater control and containment system to capture contaminated groundwater not eliminated by each option (100% groundwater containment) are given in Table 8.1-2 and shown in Figure 8.1-4. With the exception of two options (capping and diversions plus capping) the installation of an add-on pump and treat system to the other remedial options would be less expensive than operating a stand alone pump and treat system. The lowest cost option for 100% reduction in groundwater contamination is complete source removal ($750,000), whereas pump and treat is the most expensive option ($3.7 million). However, depending on groundwater conditions, the complete source removal option may require temporary groundwater containment and treatment.

8.2 PREFERRED REMEDIATION OPTIONS

Based on URS's evaluation of remedial options for the Fan Area, preferred remedial options were selected for the North and South Fan Areas. These options include the following:

- Source Removal;
- Surface Water Diversion; and
- Capping.

These preferred options were selected based upon their ability to reduce contaminated groundwater and surface water discharges to the receiving environment, cost and permanence of the solution.

8.2.1 South Fan: Selective Source Removal, Diversions and Capping

The preferred remedial approach for the south Fan (Option #11, Table 8.1-1) would potentially involve the following actions:

- Tier II Risk Assessment;
- Installation of diversion ditches upgradient of the Fan Area;
- Removal of surface deposits of concentrate, ore, tailings, sludges and waste rock;
- Removal of subsurface deposits of concentrate;
- Capping various areas with asphalt; and
- Groundwater collection from a series of wells immediately upgradient of Highway 99.

URS proposes that this remedial approach be phased in during the design and construction of the WTP. Low cost components with significant benefit (e.g. diversions and excavation of significant surface contaminant sources) would be carried out initially. Reducing surface water runoff into the Fan Area using diversions will have a significant, immediate reduction on stormwater discharges from the Mill Complex area and also reduce Fan groundwater recharge. Diversion ditches would be constructed at approximately the 4100 level elevation and at the base of slope along the eastern boundary of the Fan Area. Clean water would be directed to Britannia Creek, or by pipe to Howe Sound. If required, potentially contaminated water draining from the vicinity of the Mill Building would be piped to the WTP for treatment.

Removal of surface deposits of concentrate, waste rock and sludges should also provide an immediate and significant reduction in metals loading to Howe Sound. For example, removal of the concentrate pile located east of the Mill Building could reduce metals loading (primarily in stormwater) to Howe Sound by approximately 12%. The distribution and volume of subsurface concentrate deposits in the Concentrate Wharf area, and areas west of the Mill Building, would be delineated to determine the feasibility of their removal. Once all the surface and feasible subsurface deposits were removed and backfilled, the south Fan would be capped with an asphalt layer to prevent infiltration of direct precipitation and any runoff that was not captured by the diversion ditches. URS estimates that this combination of passive low-maintenance systems will significantly reduce groundwater flow and metals and sulphate loading, possibly reducing loading by up to 90%. If groundwater pumping and treatment were required, sludge generation from the reduced sulphate loads would be reduced by a similar amount. This could potentially result in 3,000-tonne/year reduction in sludge produced by the WTP. Assuming a $60/tonne cost for hauling this material to an on-site disposal facility results in a reduction in PV costs of approximately $3.0 million.

Ongoing monitoring would be used to assess the impact of these remedial activities. A Tier II Risk assessment would be carried out concurrently to determine site-specific risk based standards to determine an acceptable groundwater discharge quality to Howe Sound. If the monitoring and risk assessment results indicated that a groundwater collection system is still required, either in the short term until groundwater quality improved (likely within 5 years) or to mitigate continuing poor groundwater quality, the GCCS could still be installed in time for startup of the WTP.

Estimated PV cost for this remedial approach is approximately $3.1 million without groundwater capture and $6.5 million with groundwater control and containment.

8.2.2 North Fan: Surface Source Removal, Diversions and Capping

The preferred remedial approach (Option #7, Table 8.1-2) for the north Fan would potentially involve the following:

- Tier II Risk Assessment;
- Installation of diversion ditches upgradient of the Fan Area;
- Removal of the copper launder sludges in the Settling Pond;
- Capping of parts of the Ball Field area with a layer of asphalt; and
- Groundwater collection from a series of wells immediately upgradient of Highway 99.

URS proposes that this remedial approach be phased in during the design and construction of the WTP. Low cost components with significant benefit (diversions and Settling Pond excavation) would be carried out initially. Ongoing monitoring would be used to assess their impact. A Tier II Risk assessment would be carried out concurrently to determine site-specific risk based standards to determine an acceptable groundwater discharge quality to Howe Sound. Installation of a groundwater collection system would only be done if monitoring and risk assessment results indicated that it was necessary.

Estimated PV cost for this system is approximately $400,000 without groundwater control and $3.3 million with groundwater control and containment.

8.3 PERFORMANCE BASED MONITORING

On-going monitoring of Fan Area discharges will be required by BCMWLAP (as regulator). The duration and scope of the monitoring program will depend on the remedial options selected. Where GWCC is selected as the stand-alone solution, the duration of the monitoring program will be indefinite. Where more permanent solutions, such as source removal with diversions, capping are selected, monitoring may be short-term, being utilized to demonstrate the effectiveness of the remedial solutions before the monitoring program is reduced and ultimately eliminated. In order to assess the performance of remedial activities, URS anticipates the following monitoring will be required in the Fan Area:

- Groundwater: Regardless of the selected option, groundwater monitoring will be required. Discharge rate, contaminant concentrations and contaminant flux will have to be monitored on at least a quarterly basis. A performance monitoring program and reporting will be required to demonstrate the effectiveness and maintenance of groundwater control. Further hydrogeologic studies may be required as part of the program to determine the effect of tides and Britannia Creek on Fan Area groundwater.
- Surface Water: Britannia Creek and any uncontrolled surface water discharges will have to be monitored to verify impacts have been controlled or eliminated. This program may be of finite duration, but could still last many years if non-permanent solutions are selected.

- Intertidal Monitoring: Assessment and monitoring of biologic activity in the foreshore area would provide a reliable method of judging the impact of any remedial activities. Monitoring on an annual or semi-annual basis would be instituted until conditions were sufficiently improved and met acceptable regulatory standards.
- Soil containment system monitoring: If source removal and on-site disposal is selected, monitoring of the containment facility will be required. This will include visual inspection of the facilities and monitoring of groundwater / surface water conditions surrounding the facility.
- The cost of an annual monitoring and reporting program has been estimated to be at least $100,000 in current dollars, or $2 million in terms of net present value for an indefinite program, or $500,000 for a 5 year program.

8.4 Required Additional Studies

URS has provided a listing of additional studies that would provide increased certainty to the remedial planning for the Fan Area.

8.4.1 Longer Duration Pumping Test

Current estimates of groundwater extraction rates required to achieve full and partial containment of Fan area groundwater are based on short-term pumping tests in two locations within the Fan, and on preliminary water balance calculations. In order to gain more certainty regarding these estimates, URS would need to conduct longer term pumping tests, preferably at higher pumping rates, to better understand large-scale aquifer behaviour. Such tests may be possible during the next plug test when there would be capacity in the permitted mine discharge to Howe Sound for pump test water.

8.4.2 Kinetic Testing of Residual Mine Wastes

The proposed remedial option for the Fan Area involves the selective removal of mine wastes with the highest potential metal loading rates, including sludges, concentrates, tailings and low grade ore. Waste rock, with low potential loading rates, will be left in situ. The waste rock will continue to oxidize and/or leach metals, but at significantly lower rates than the more reactive mine wastes. However, in the Concentrate Wharf area, metal-rich oxidation products may have accumulated in the waste rock as a result of the precipitation of secondary minerals originating from acidic, metal-rich groundwater flow from upgradient sources. Following removal of the high metal load sources, continued groundwater flow through the impacted waste rock may result in a significant, but likely finite, source of metals loading to the receiving environment. Reduction of this impact could require a temporary pump and treat system to meet water quality objectives in the receiving environment. The operational duration of this system is not known.

In order to assess the impact of these materials on the receiving environment and determine the potential requirements of a temporary treatment system, laboratory column tests should be set up to simulate groundwater flow through waste rock in the Concentrate Wharf area. Data from these tests will be used, along with on-site monitoring data, to determine the need for additional remediation; and if required, the expected operational duration of a pump and treat system.

8.4.3 Fan Area Water Balance

Present estimates of groundwater and surface water inputs and outputs are based on a rudimentary desktop water balance. A more detailed, field verified water balance will be required to design proposed remedial structures such as diversion ditches and stormwater runoff systems. Further, a calibrated water balance will be necessary for measuring the effectiveness of remedial activities such as diversions and capping in reducing surface water and groundwater flow.

8.4.4 Tier II Ecological Risk Assessment

The Tier I ERA assessed the ROC and COCs for the Fan Area. The conclusions stated that there is potential adverse effects, thus risk, to some ROCs in the terrestrial and aquatic environments from the COC (particularly copper and zinc) concentrations found in the soil and water in the Fan Area. Therefore, a Tier II ERA is required to refine the ROCs and COCs for the site and to further assess the risk to ROCs in the terrestrial and aquatic environments from the COCs in the Fan Area. The Tier II ERA will recommend risk-based standards for the soil and water. These risk-based standards can then be used as benchmarks to monitor success of remedial actions on the site on the soil and water (marine and freshwater). When the Fan Area soil and water meet the risk based standards a Conditional Certificate of Compliance from BCMWLAP may be issued for the site.

8.4.5 Surface Water Current Studies

The hydrodynamics of surface water have a direct effect on resulting COC concentrations in Howe Sound, yet these dynamics are as yet not well understood. A greater understanding will be required to enable an assessment of the relative effects of the following COC sources on Howe Sound water quality:

- groundwater discharge from the Fan Area;
- surface water from Britannia Creek;
- storm runoff; and,
- the deep outfall.

To this end URS recommends the collection of current data in the Britannia Bay area to facilitate a study of the relative significance of these sources, and to better understand the assimilative capacity of Howe Sound. Current data would be used to develop a more sophisticated mixing model (CORMIX). This model could be used to more accurately predict resultant COC concentrations in Howe Sound as a function of distance from the Fan Area shoreline, and would allow for an assessment of tidal pollutant build-up potential.

9.0 REMEDIATION PLAN IMPLEMENTATION

9.1 CONSULTATIVE AND IMPLEMENTATION PROCESS

To develop and implement a successful remedial plan for the Fan Area, URS believes that thorough consultation with stakeholders and the public will be necessary. Some of the proposed remedial activities that have a limited impact on stakeholders and the public can likely be initiated quickly with a minimum of consultation. However, some of the more extensive and invasive remedial activities will require a greater level of input from stakeholders/public representatives.

9.2 SCHEDULE FOR IMPLEMENTATION

URS believes that remedial activities can be instigated well before the WTP is scheduled to begin operation in April 2004. For example, under the preferred South Fan Option (Selective Source Removal, Diversions and Capping), many of the lower cost remedial activities (e.g. diversions and surface source removal) could be completed within several months of approval. This would result in immediate and significant reductions in metals loading to Howe Sound. More extensive, costly or invasive remedial activities would be implemented following consultation with stakeholders and the public.

Figure 9.2-1 presents a proposed schedule for carrying out the remedial activities in the Fan Area. Key components of this schedule are immediate measures designed to reduce loading from surface sources and to divert clean surface water from the Fan Area prior to the spring 2003 freshet. Additionally, more invasive remedial activities (subsurface source removal and capping) are proposed to be completed before the onset of the late Fall-Winter 2003 heavy rainfall period.

Performance-based monitoring should be instigated prior to any significant remedial activities in order to accurately assess their impact on loading to the receiving environment. This monitoring should be conducted until site-specific remediation objectives are achieved.

10.0 STANDARD LIMITATIONS

The findings and conclusions documented in this report have been prepared for specific application to this project and have been developed in a manner consistent with that level of care and skill normally exercised by members of the environmental science profession currently practising under similar conditions in the area. No other warranty, expressed or implied, is made. This report is for the exclusive use of BCMWLAP and their representatives.

11.0 DISCLAIMER

In the event that this report is provided in electronic format, URS is not responsible for uses of the data outside of or beyond the scope of our original agreement with our client. Our paper report represents our official work product. Also, because data stored on electronic media or transmitted by electronic means can deteriorate undetected or be modified without URS's knowledge, URS is not liable for the compatibility, completeness or correctness of the data.

12.0 PROFESSIONAL STATEMENT

The information compiled for this document has been prepared in accordance with the requirements of the Waste Management Act and its Regulations.

URS certifies that the persons signing this document have demonstrable experience in the assessment of commercial sites. The work has been performed by URS staff under the guidance and supervision of the signatories below.

Thank you for selecting URS for this project. Please call the undersigned at (604) 681-1672 if you require any clarification.

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TABLES

FIGURES

APPENDICES

APPENDIX NOT FILMED

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